DISCOMFORT GLARE

LUMINAIRE LIGHT DISTRIBUTION, VEHICLE SPEED AND BACKGROUND IN A DYNAMIC ROADWAY LIGHTING SIMULATION

BY

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INTRODUCTION

The primary objective of roadway lighting is to ease the complexity of the driving task and to create a night-time environment conducive to quick, accurate and comfortable seeing for the motorist. Efficient roadway lighting should give a degree of safety and driving comfort for night traffic that is not inferior to that experienced in day time under comparable conditions, so that the traffic capacity of the road at night is, as much as possible, equal to that in the day time. It is, of course, impossible to reproduce optimal daytime conditions. The lighting research on roadway lighting has been directed to what minimum requirements must be fulfilled by roadway lighting in order to provided secure, safe, and comfortable night driving.

The important factors in the quality of roadway lighting are :

(1) Disability glare.

(2) Discomfort glare.

(3) Pavement luminance.

(4) Light on vertical surfaces.

(5) Uniformity of horizontal and vertical illuminations, as well as uniformity of pavement luminance and other background areas.

Glare in Roadway Lighting

Light that produces discomfort and sometimes interference with visual ability is known as glare. The

glare caused by light sources in the field of vision is known as direct glare, whereas the glare caused by reflection of a light source on a viewed surface is known as reflected glare or veiling reflection.

Glare from the roadway light sources may be defined as (De Boer 1967) :

> "When the field of the vision of an observer contains a light source whose luminance in the direction of the observer is appreciably greater than that of the other parts of his field of vision, this light source will give rise to glare. The glare produced increases with the luminance and apparent size of the light source, and with decreasing luminance of the background and the angle between the direction of observation and the direction to the light source".

Glare Effects

There are two forms of glare effects, disability and discomfort glare.

Disability Glare, which may not be apparent to the observer, acts to reduce the ability to see or spot an object. Sometimes it is referred to as "veiling glare" or "blinding glare". The evaluation of disability glare is based upon the Holladay (1925) formula and is expressed by calculating the increment in the threshold of detection of the luminance difference between the relevant object and road surface (Adrian 1961 and 1975, Fisher and Christie 1967, Fry 1955, Hartmann 1963 and 1968). According to the formula, the glare effect is described by an equivalent uniform luminance resulting from the stray light in the eye

which superimposes on the location of the retinal image thus lowering contrast. The equivalent veiling luminance L_v may be expressed by :

$$L_v\ (\text{total}) = K \frac{E_{1\,Gl}}{O_1^{\,2}} + K \frac{E_{2\,Gl}}{O_2^{\,2}} + \ldots.$$

where,

L_v = Veiling luminance, cd/m_2.

K = 10, Constant.

$E_{i\,Gl}$ = The illuminating on the observer's eye produced by the glare source in the plane perpendicular to the line of sight, lux.

O_i = Angle between the center of the glare source and the line of sight, degrees.

<u>Discomfort Glare</u> produces a sensation of discomfort but does not affect the visual acuity or the ability to discern an object. Discomfort glare can be quantitatively described by a Glaremark score (Figure 1) which can be calculated from the photometric and geometric quantities of a lighting installation (De Boer and Heemskerck 1955, De Boer and Schreduder 1967, Adrian and Eberbach 1965, Adrian and Schreduder 1970 and 1971, and Adrian 1975).

It is generally true that when disability glare is reduced, there also will be a reduction in discomfort glare, but not necessarily in the same degree. However, if the discomfort glare is acceptable, hardly any effect on visual performance may be expected.

Glaremark Rating Scale

9	UNNOTICEABLE
8	
7	SATISFACTORY GLARE
6	
5	JUST ADMISSIBLE
4	
3	DISTURBING
2	
1	UNBEARABLE

Figure 1 : Glaremark rating scale

While both forms of glare reactions are caused by the same light flux, the many factors involved in roadway lighting (such as source size, displacement angle of the source, illumination at the eye, adaption level, surround luminance, exposure time, and motion) do not affect both forms of glare in the same manner, nor to the same degree. The only two factors common to both forms of glare are illumination at the eye and the angle of flux entrance into eye. Even these factors have varying effects on the two forms of glare. It is generally true that when disability glare is reduced, it follows that there also will be a reduction in discomfort glare, but not necessarily in the same relative amount. On the contrary, it is entirely possible to reduce the discomfort glare of a system but, at the same time, increase the disability glare. Since a functional connection between the two forms of glare is, at present, not known the two forms of glare are treated separately in research. The discussions in this thesis deal with discomfort glare from fixed roadway lighting.

Borderline Between Comfort and Discomfort

Borderline between comfort and discomfort (BCD) can be defined as " somewhere between the two sensations of comfort and discomfort of the light there is a point of change, a threshold ".

Luckiesh and Guth (1949), Putnam and Facett (1951) and Bennett (1977) conducted experiments to arrive at the BCD

levels for various combinations of parameters. In Bennett's (1977) study, he determined a relationship for BCD :

$$BCD = \frac{40\ (\ LB^{0.3}\ )\ (\ e^{0.05 * A}\ )}{S^{0.6}}$$

where,

BCD = The borderline between comfort and discomfort, foot-lamberts.

A = The source angle above of line of sight, degrees.

LB = The background luminance, foot-lamberts.

S = The source size, steradians.

e = Constant, 2.718.

The research by Putnam and by Bennett used small source sizes with primary applications to exterior lighting such as roadways.

Methods of Evaluation of Glare

Subjective Appraisal This method had observers asked for their subjective impressions about the glare. In the earliest work (Luckiesh and Holladay, 1925), the procedure was to ask the observer to alter the luminance of the glare source to give, in turn, a series of sensations of discomfort or comfort. A very large number of sensations ranging from "painful" to "very pleasant" were used. Hopkinson (1940) developed a method which employed a series of four criteria of discomfort glare (Glaremark - just perceptible, just accepted, just uncomfortable, just intolerable), associating with these criteria a method of

'calibrating' the observer over a long period so that his evaluation could be improved in precision by experience, and the variance of the evaluation about a mean could be determined.

Objective Adjustment In this method, the observer is asked to think about the situation, evaluate it, and make a setting of a controlled variable, such as the glare source luminance or background luminance, until the glare sensation corresponded to a criterion which has been described to him and which he believed he could reproduce. Studies have shown that subjective assessments tend to close to the middle of the available range. (This is known as a range effect.) Range effects are a general characteristic of a person in an experiment with a within-subject design. Lulla (1976) found that the luminance range made available to the subject does have an effect on the evaluation of BCD.

Method of Presenting Glare

Continuous Viewing With this straight-forward technique, the observer simply looks directly at the light source during the entire period of judgement or adjustment (Atkinson 1966, Bennett 1971).

Momentary Viewing With this technique, the light source is presented to the observer in a periodically on and off cycle. This technique was devised as a simulation of the common situation where the observer in engaged in some activity (not looking at the source directly) and then

glances at the source momentarily (Guth 1950, Bennett 1971).

Bennett's (1971) study found that momentary viewing yields higher BCDs than continuing; this was not compatible with Atkinson (1966).

Multiple Sources

The real roadway situation and prior study show the importance of multiple sources. Luckiesh and Guth (1949) conducted a study to determine the relationships that can be used to establish the BCD of multiple sources. They found that two sources of equal brightness and area, located symmetrically on the either side of the line of the vision, are equivalent to a single source of the same brightness having a total area of both sources and located at the point where one of the two sources was located.

Using the discomfort glare caused by multiple sources in interior lighting, Guth and McNelis (1961) said that the usual procedure for obtaining discomfort glare ratings for a complete lighting system is to sum up the computed glare ratings of the individual luminaries of luminous elements.

Bennett (1979) conducted research on a linear array of multiple sources for a particular simulated set of lights. He showed that the influence of lights declined as one looked farther down the roadway. This led to a "cumulative brightness" model where summation of effects for size, position and background over successive lights is used. This is the current CBE procedure.

Individual Differences

"No two people are identical" is a well known fact. It has been a common experience and concern of glare researchers to find very wide individual differences in sensitivity to glare.

Luckiesh and Guth (1949) conducted a study to find the BCD brightness of a standard circular source, located on the line of sight, with a constant background luminance. They concluded that the variation between individuals is not unexpected nor extraordinary because of the many physiological and psychological factors that may influence the subjective appraisal of brightness areas. Furthermore, the standards of comfort and discomfort vary greatly among individuals.

Alphin (1961) reported that there was no relation between age and the brightness chosen for BCD. Neither eye color nor the wearing of eye glasses had any correlation with the brightness selected for BCD.

Bennett (1977) conducted a correlation study between discomfort glare judgments and age, eye color, occupation, sex, resident population, place of residence, hair color and wearing of glasses. He found a small correlation between BCD and age (-0.31), eye color (0.16) and occupation (0.17). Those with outdoor occupations had higher BCD.

Bennett (1977) constructed a model for predicting BCD from source size, source angle and background luminance. He

found that individual differences among the subjects were very large and of equal importance in predictiveness to the physical parameters.

Pupil Response

Research has been carried out in an attempt to relate discomfort glare to physiological changes produced by the glare sources.

Hopkinson's (1956) research indicated that the diameter of the pupil of the eye was not related directly to the sensation of discomfort which results from a brightness source in the field of view.

Fugate and Fry (1956) have shown that, under certain conditions, discomfort glare is related to the activity of the muscles which control the diameter of the pupil. While light reduces the size of the pupil, Fry and King (1971, 1975) found that (1) it is not the size alone that generates discomfort, rather it is the fluctuation in size, when the kind of control of the pupil response is affected by momentary and intermittent stimulation, and (2) in case of a steady source the discomfort had to depend on the fluctuation in the constrictions of the sphincter muscles of the iris which occurred in response to steady simulation by light.

Prediction Systems

Glaremark System   The current method for quantification of discomfort glare in Europe is based

primarily on the experimental work carried out by Adrian and Schreduder (1970).

In this empirical model, the observer's position along the roadway is not relevant; it makes no difference to Glaremark if the observer is in any lane or whether he is moving or is static. The calculation of Glaremark was done using the following empirical formula :

$$GM = SLI + 0.97*\log(L) + 4.41*\log(h) - 1.46*\log(P)$$

$$SLI = 13.84 - 3.31*\log(I\_80) - 1.31*\log(I\_80/I\_88)^{0.5} - 0.08*\log(I\_80/I\_88) + 1.29*\log(F)$$

where,

GM = Glaremark score.

SLI = Specific Lantern Index.

I_80 = Luminous intensity of the lantern at an angle of 80^0 to the vertical, candelas.

I_88 = Luminous intensity of the lantern at an angle of 88^0 to the vertical, candelas.

F = Flashed area of the luminaire as viewed from 76^0 to the downward vertical, m^2.

L = Average road surface luminance, cd/m^2.

h = Height of the luminaire above the road minus the observer's height, meter.

P = A quantity based on the number of luminaires per kilometer of the road, dimensionless.

Cumulative Brightness Evaluation (CBE) System At Kansas State University, a series of investigations has

shown that the cumulative effect of a number of equal brightness sources can be combined (Bennett, 1979). The effect of several sources of differing brightness and location can be expressed in the terms of a "Cumulative Brightness Effect" (Bennett, 1980).

The system is an observer oriented system. Its value varies depending on the lane in which the observer is located and his position along that lane. The equation as developed, based on the suggestion by Dr. Glenn Fry using data at Kansas State University, is as follows :

$$CBE = \frac{(B1^{1.67}) * S1}{e^{0.08 * A1}} + \frac{(B2^{1.67}) * S2}{e^{0.08 * A2}} + \ldots\ldots\ldots$$

Where,

B = Photometric brightness of the glare source, FL.

S = Source size, steradian.

A = Source angle off the line of sight, degrees.

e = Constant, 2.718.

<u>Research on Discomfort Glare at Kansas State University</u>

The discomfort glare research at Kansas State University is to provide a basis for a North American system. The research, started in the fall of 1970, can be divided into three periods, i.e, early period (1970 - 1976), intermediate period (1976 - 79) and present period (1979 - present).

<u>Early Period</u> In this period, the research included (1) different viewing techniques and source sizes (1971), (2)

BCD vs. borderline between pleasantness and comfort (Bennett 1972), (3) the effect of instruction (Bennett 1972), (4) relationship of task type and glare judgement (Bennett 1972), and (5) demographic variables (Bennett 1972, Bennett 1974, Bennett 1976 and Bennett 1977).

<u>Intermediate Period</u> The research in this period was concentrated on (1) study of angularly small sources (Bennett 1976, Bennett 1977, Bennett and Rubison 1979), (2) range effect (Lulla 1978), and (3) stability of individual sensitivity (Bennett 1979).

<u>Present Period</u> The research was shifted mainly to the study of roadway lighting. It was (1) multiple sources in roadways (Bennett 1979, Bennett 1979 and Bennett, Rubison and Ramaro 1984), (2) personal control and task difficulty (Anand 1983 and Madhavan 1983) and (3) dynamic roadway lighting simulator (Anantha, Dubbert and Bennett 1982, Anantha 1982, Easwer, Dubbert and Bennett 1983, Bennett 1983, Easwer 1983, Hussain 1983, Hussain 1985, Ganesh 1985, Ganesh 1986).

PROBLEM

Experiment 1 was used to select qualified subjects for experiment 2. The effect of initial luminance and amount of practice on the subject's adjusted BCD was examined. The relationship between the time of the subject adjusting the luminance level to the BCD point and the variance of the subject's BCD also was explored.

The goal of experiment 2 was to validate the unexpected finding of Ganesh (1986). Ganesh found that luminaires with a filter (realistic luminaire) to reduce their brightness when seen at a distance (luminaire distribution runback) were less comfortable than luminaires (constant luminaire) which had the same brightness regardless of distance. This is contrary to conventional knowledge which holds that sharp cutoff luminaires (fast distribution runback) should be more comfortable. Real streetlight luminaires are designed to have very low candlepower at 90^0 and have their maximum candlepower at approximately 70^0 from nadir. A luminaire seen in the far distance is seen as small in size; as approached, it increases in size. It reaches its maximum brightness just before it disappears above the top of the windshield (approximately 70^0 in term of the luminaire distribution). The rate at which the candlepower is reduced as the angle changes from 70^0 to 90^0 is termed the "runback". Apart from two luminaires mentioned above, another type of luminaire (90^0 maximum candlepower system)

was investigated. We investigated the sensation of glare among the three luminaires, and the relationship between the CBE system and Glaremark system.

Another part of experiment two was to explore the effect of "car speed" in greater depth and the effect of changes in luminance of the roadway background on the sensation of glare comfort.

The goal of experiment 3 was to find if there is any correlation between Pupil Size Index (PSI) and the observer's subjective determination of BCD. If there is a relationship between them, PSI can be used as an objective index for BCD.

METHOD

Simulator

Principles of Dynamic Simulation The basic concept of the simulation is that of a disk rotated in front of a light source. The disk has a clear spiral which increases in width as it spirals outward. The disk is opaque except for the clear spiral track.

An occluder with a narrow open sector occludes most of the disk. As the disk rotates behind the occluder, the observer sees a series of "roadway lights" from the large first light above him to the ever more closely spaced small lights near the horizon. The basic concept was developed further to a new concept in 1983.

The new concept was that the two disks rotate in opposite directions (in proportion to the "vehicle speed") behind the occulder. The disks are opaque except for clear double-spiral tracks on each of them (Figure 2). The occluder is opaque except for the two narrow sectors. Both the disks and occulder are in front of the light source. On the several places where the two sectors and the double-spirals on each disk intersect, a series of "street lights" (Figure 3) occur. These appear to move forward and above the driver, getting larger.

The new concept was used in developing a dynamic simulator at Kansas State University (Easwer, Dubbert, and Bennett, 1983). Table 1 shows the relationships between the

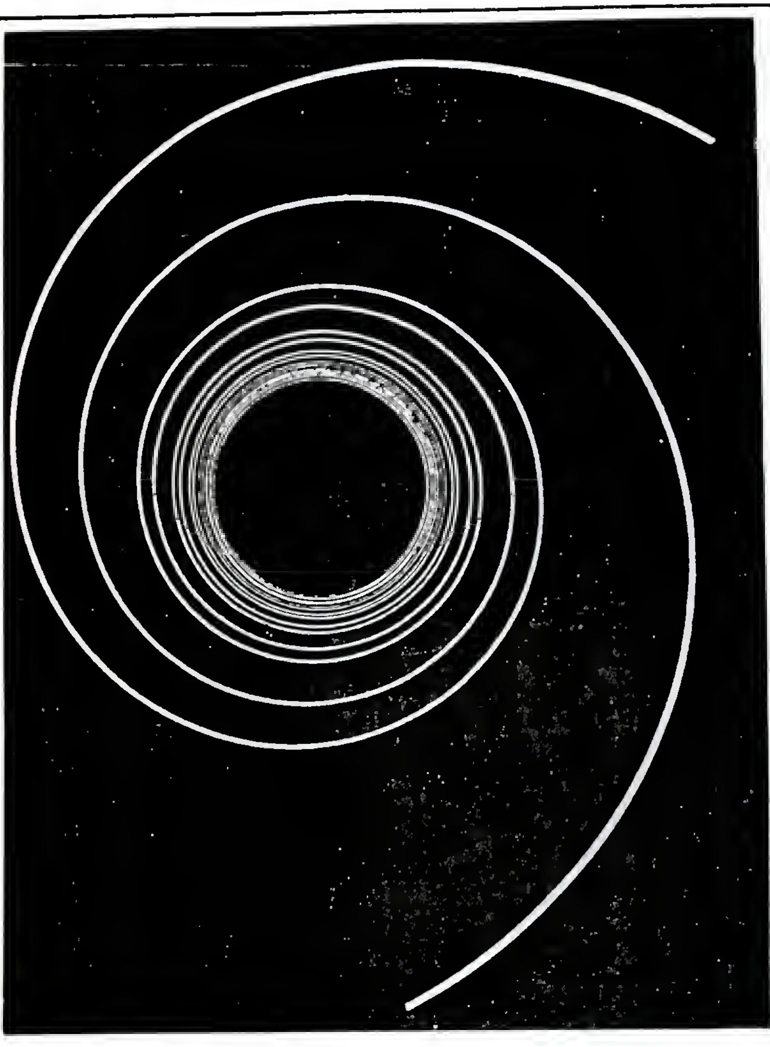


Figure 2 : Clear double-spiral tracks

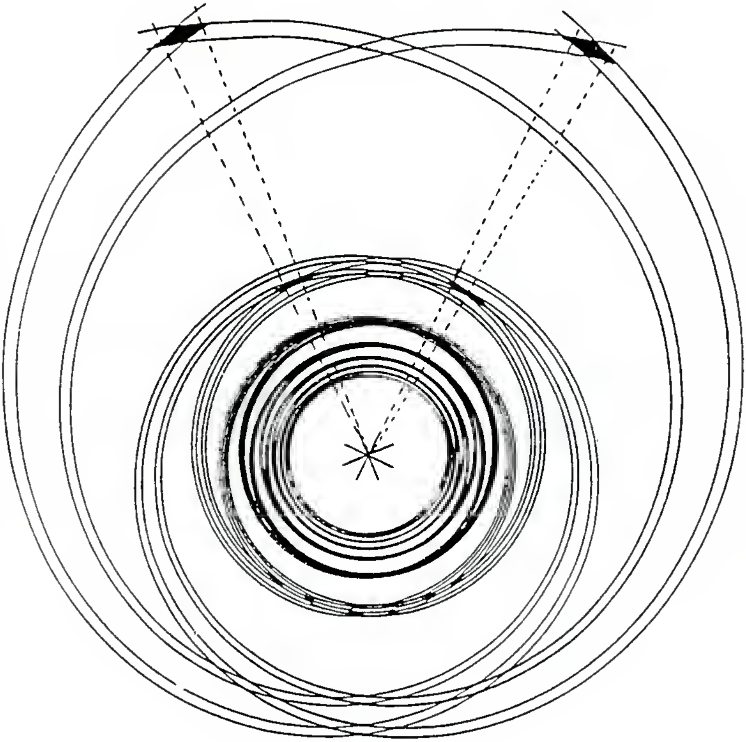


Figure 3 .: Intersection of double spirals

Table 1 : Real world conditions vs. simulation conditions.

Real world conditions		Simulation conditions
1)	Speed of the car, mph	Rotational speed of the disk, rpm
2)	Angular distance from the observer's line of sight to road light, degrees	Angular distance from the observer's line of sight to the spiral segment, degrees
3)	Distance from the motorist to the light poles, feet	Rotational speed of the disk, rpm
4)	Horizontal dimension of the luminaire, feet	Width of the narrow open section in the opaque mask, inches
5)	Vertical dimension of the luminaire, feet	Width of the spiral in the radial direction, inches

roadway lighting conditions and the simulation parameter. A side view of this simulator is shown in Figure 4. The simulator is a driver portion of an older car and is completely sealed from the outside. That is, light from outside cannot enter the inside. The only light a subject can see is the simulated road lights. The room is lighted by a 25 Watt red light bulb during any change of condition so that there is no change in the subject's dark adaption due to the room light.

Roadway Lighting Selection The simulated roadway lighting installation was the "McCall Road" in Manhattan, Kansas. It is scaled to have all luminaires on one side of the road with the spacing between luminaires equal to 210 feet and the mounting height equal to 30 feet. The type of luminaire is Cobra Head / High Pressure Sodium.

Modification of Dynamic Simulator Modifications made on the existing simulator during 1988-1989 were as follows :

(1) Light leaks that affected the luminance of the "sky and roadway" scene were sealed. The solid metal side access was replaced with a black curtain to make the change of the condition easier and less time consuming.

(2) The simulator was raised by 3.8 inches. The existing car seat was removed and the sheet metal under the driver was cut to provide a 22 inches by 38 inches hole. A adjustable seat was installed in the hole. This allowed standardizing the vertical height of

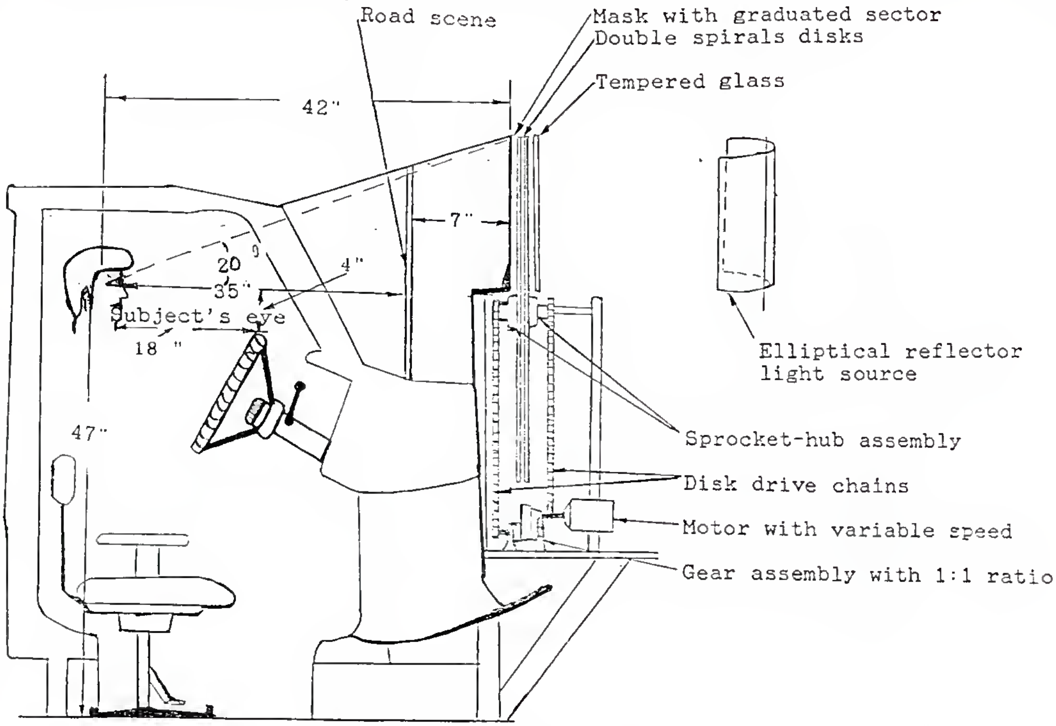


Figure 4 : Side view of simulator

subject's eyes to the intersection of the roadway at the horizon of the scene.

(3) The dash and steering wheel were lowered by 2 inches to increase the viewable area of the painted scene.

(4) The existing rough surface glass diffuser covering the lamp troughs was replaced with a smooth surface diffuser that did not "sparkle". The transmittance for the smooth tempered surface diffuser is 7%. The calibration chart (clear glass + smooth surface glass + one pair of clear discs) is shown in Figure 5.

(5) The method of holding the occluder was modified. The occulder was held on only one side. This makes the change of the occluder easier.

(6) A background scene was provided. It was placed 35 inches in front of the driver's eyes.

Preparation of Simulator The above mentioned simulator was used in experiment 2. That is, the subject "drove" the simulator using the McCall road disc. The McCall road condition represents a "single-sided" installation. A typical cobrahead luminaire is shown in Figure 6. Figure 7 gives the isofootcandle line of horizontal illumination of the cobrahead luminaire. Figure 8 gives the candlepower tables for the luminaire selected.

The existing two disks with a double spiral for the luminaire were developed by Hussain (1985). The two disks

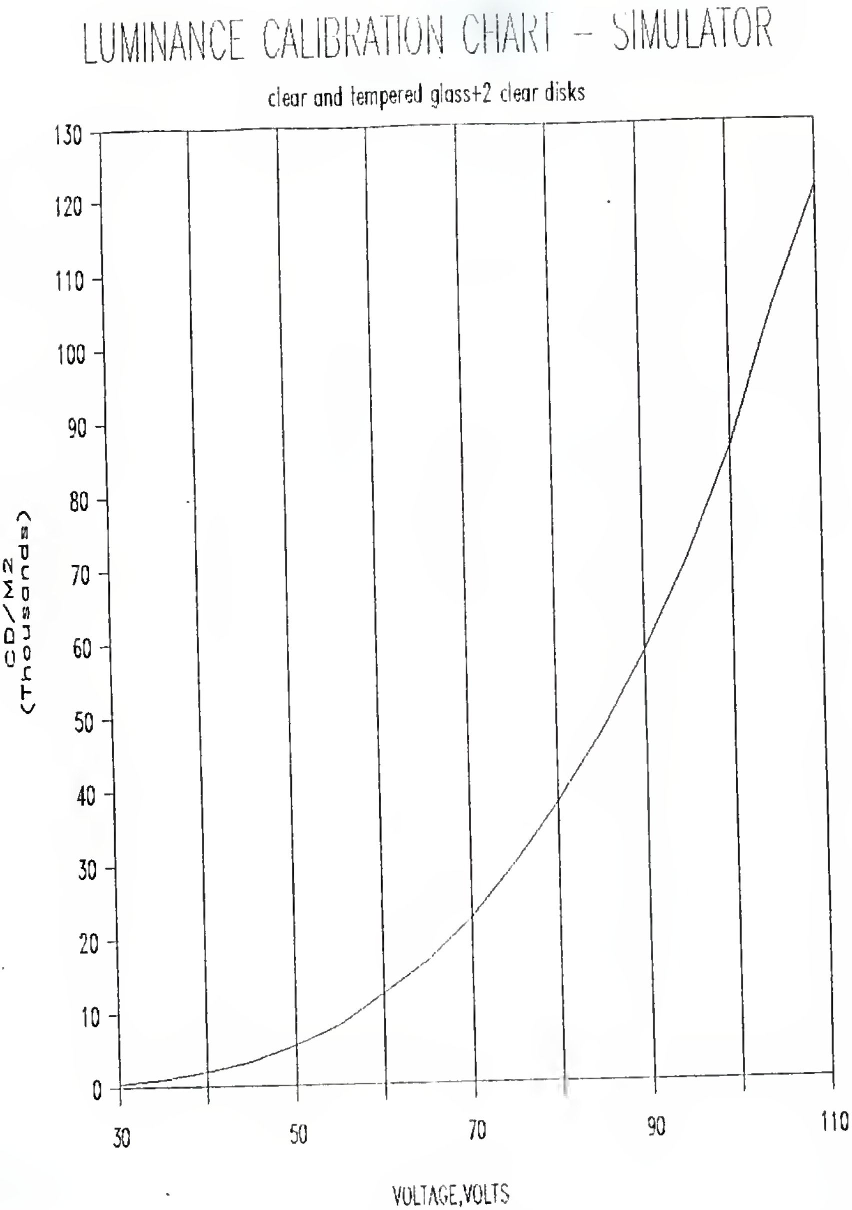
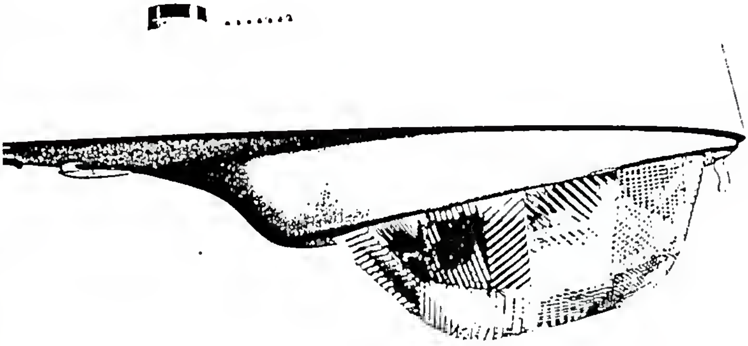


Figure 5 : Luminance calibration chart - simulator

Horizontal Luminaire

High Pressure Sodium—200 to 400 Watts, Mercury Vapor—400 Watts,
Metal Halide—400 Watts
SERIES: 25 and 26



ITT OUTDOOR LIGHTING
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Figure 6 : Cobrahead luminaire

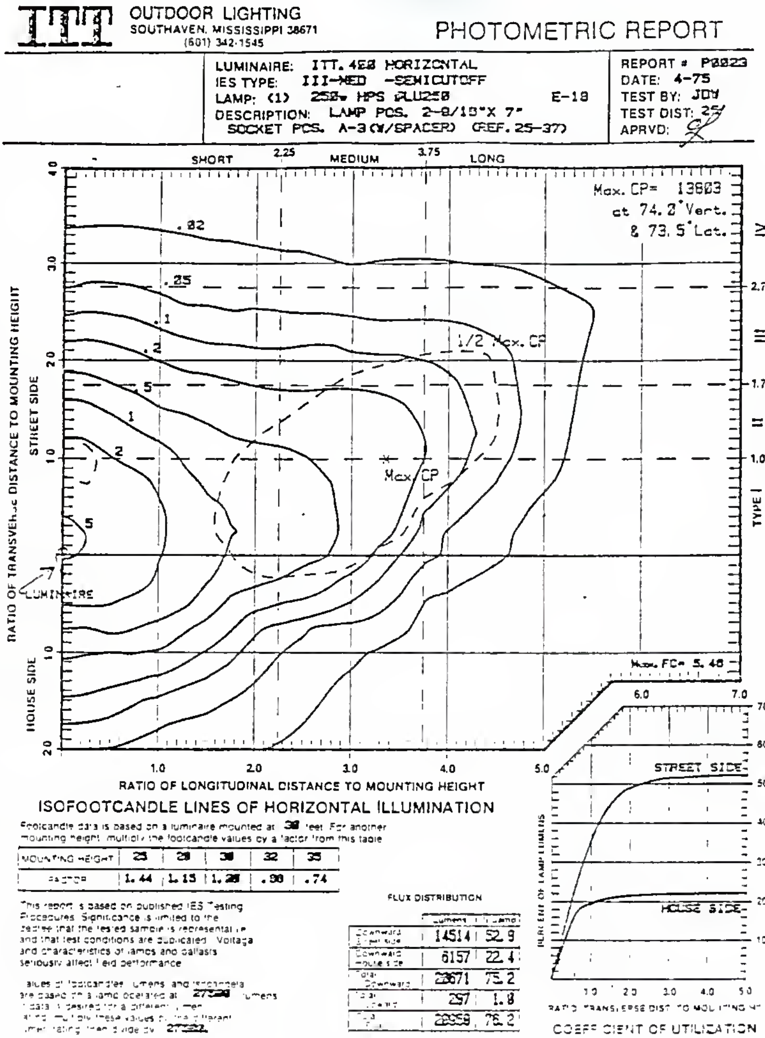

Figure 7 : Isofootcandle lines of cobrahead luminaire

CRITICAL CANDELA DATA (04)

	60.0	62.5	65.0	67.5	70.0	72.5	75.0	77.5	80.0	82.5	85.0	87.5
52.5	2403	2429	2434	2434	2337	2290	2290	2306	2403	2409	1822	1235
57.5	2892	2985	3129	3232	3186	3108	3304	3567	3664	2995	1971	1235
62.5	3325	3587	3880	4055	3973	4143	4786	5172	4498	3186	1925	1209
67.5	3685	4071	4477	4483	4658	5322	6212	5996	4508	2975	1786	1153
72.5	3788	4302	4493	4472	5188	6268	6690	5651	3901	2506	1549	1024
77.5	3567	3963	3953	4210	5342	6402	5939	4503	2980	1925	1235	834
82.5	3047	3201	3201	3736	4966	5455	4344	3062	2028	1364	896	623
87.5	2419	2439	2553	3175	4184	3999	2784	1930	1287	896	618	448
92.5	1909	1889	2059	2614	3253	2671	1698	1158	793	582	422	324
97.5	1518	1503	1642	2033	2311	1704	1060	731	515	396	304	242
102.5	1215	1199	1276	1467	1529	1096	695	494	371	293	237	196
107.5	993	978	983	1024	1009	746	504	376	288	232	190	160
112.5	870	839	787	746	690	546	391	299	237	196	165	139
117.5	777	741	664	561	494	412	319	247	206	170	144	134
122.5	726	674	566	432	355	324	268	221	185	149	129	113
127.5	674	623	484	350	273	252	226	185	154	139	118	108

Figure 8 : Candlepower data for cobrahead luminaire

CANDELA DATA (02)

HORZ ANGLE	VERTICAL ANGLE >>----> 0.0	5.0	15.0	25.0	35.0	45.0	55.0	65.0	75.0	85.0	95.0	105.0
0.0	1349	1585	1832	1626	1426	1086	1255	1261	380	226	144	103
5.0	1349	1575	1796	1652	1400	1009	1065	1086	427	226	144	103
15.0	1349	1565	1760	1678	1374	932	875	911	474	226	144	103
25.0	1349	1539	1770	1750	1508	1086	834	782	551	278	160	103
35.0	1349	1503	1765	1868	1951	1616	1312	1101	829	540	226	113
45.0	1349	1467	1729	1961	2141	2105	1868	1642	1441	1235	288	118
55.0	1349	1431	1668	1791	2033	2239	2419	2779	2795	1894	314	129
65.0	1349	1395	1570	1359	1755	2357	2897	4179	5496	1853	319	134
75.0	1349	1354	1462	1034	1719	2162	2820	4220	6310	1390	283	139
85.0	1349	1318	1318	839	1420	1673	2167	2872	3561	751	221	134
95.0	1349	1256	1179	710	1153	1297	1559	1348	1379	360	165	118
105.0	1349	1220	1029	618	916	988	1070	1127	597	211	129	93
115.0	1349	1173	896	576	762	793	834	726	355	149	103	77
125.0	1349	1143	777	571	679	710	710	525	247	118	87	62
135.0	1349	1112	700	607	669	700	654	396	170	108	77	52
145.0	1349	1091	643	654	705	695	618	381	144	98	67	52
155.0	1349	1076	633	684	731	695	587	381	154	87	62	46
165.0	1349	1065	633	721	772	705	587	381	175	82	62	41
175.0	1349	1055	628	741	793	721	597	396	180	87	57	41

Figure 8 : Isofootcandle lines of cobrahead luminaire
(Continued)

having the same double spiral track, offset from one another by an angle of 52^0 and rotated in the opposite direction, simulated the roadway lights from the installation.

One graduated sector was made for the installation. The dimension of the sector was determined by taking into account the dimension of luminaire and using a linear relationship (assuming that as the driver moves toward the luminaire, the dimensions of the luminaire increases linearly).

One light fixture was used in line with the open sector to simulate the luminance of the real-world fixture. The light fixture used five 300 Watt quartzline lamps covered with a heat resistant glass on the front side. All the lamps were arranged in the simulator in a stacked configuration, with the filament of each bulb positioned at the focus of the elliptical reflector made of a sheet of tin. The elliptical reflector increased the efficiency of the light source by concentrating the light from the quartzline lamp on a long, narrow piece of the smooth tempered surface diffuser. The net effect was to provided a long narrow bar of intense and well diffused light. Intensities as high as 121,000 cd/m^2 can be obtained by this system.

Finally the rotational speed of the disk (simulating the speed of the car) was calculated using the formula as follows :

$R = 88 \, (M/S)$

where, R = the rotational speed of spiral, rpm

M = the speed of the car, mph

S = the pole spacing, feet

It was derived from the fact that one revolution of the spiral corresponds to a distance travelled of one space between poles. If S is the pole spacing in feet, then S/minute corresponds to 1 rpm of the spiral. Therefore, the rotational speed of the spiral, to simulate a driving speed of M mph, is derived as follows :

1 rpm = S/min,

1 rpm = S ft/min x miles/5280 ft x 60 min/hour,

= S/88 miles/hour (mph),

1 mph = 88/S rpm,

R rpm = 88/S x M mph.

Table 2 shows the disk rotation speed corresponding to the car speed.

Design of Luminaires

Three luminaires conditions were simulated : 1) realistic luminance, 2) 90^0 maximum candlepower luminance and 3) constant luminance.

Calculation of Luminance We used the computer program developed by Merle Keck to calculate the glare component from each luminaire. We then summed the components to produce the "Cumulative Brightness Evaluation" (CBE) of all the luminaires in the system. This CBE for an observer is

Table 2 : Car speed vs disk rotation speed.

M, Car speed, mph	R, Disk rotation speed, rpm
40	17
50	21
60	25

calculated as the observer is moved though the system. The calculation was based on the luminaires on one side of the roadway with 210 foot spacing; the observer moves through the system at 30 foot increments. The effect is to produce a sawtooth curve with the highest value occurring just before a luminaire disappears from view (due to the cut-off of the car windshield). The lowest value occurs just after the luminaire has disappeared; the CBE then rises as the next luminaire advances towards the observer. The input data and the CBE value of three types of luminaires at different observer locations are shown in Table 3.

Criteria for Evaluating the Lighting System The figure of CBE vs observer location is shown in Figure 9. The CBE summary for three types of luminaire is shown in Table 4. The realistic luminaire and the constant luminance luminaire will produce identical maximum CBE impact (CBE = 879). The constant luminaire system has a much higher minimum glare value (CBE = 306) vs CBE = 26 for the realistic luminance system. The 90^0 maximum candle power system also has a very low ratio of maximum to minimum glare. The area under the curve was integrated by dividing the observer location into 1 foot segments, calculating the area and adding up areas from 0 to 420 feet (2 cycles of CBE change). The 90^0 maximum candle power system (area = 149,000) has a larger area under the curve than the real luminaire (area = 104,000) but smaller area than the constant luminance system

Table 3 : CBE calculations for 90^0 maximum candlepower, realistic and constant luminance. For the McCall road, 8 luminaires mounting height was kept constant at 30 feet and orientation at 270^0. See Figure 9.

Lum. No.	X, feet	Y, feet
1	20.0	210.0
2	20.0	420.0
3	20.0	630.0
4	20.0	840.0
5	20.0	1050.0
6	20.0	1260.0
7	20.0	1470.0
8	20.0	1680.0

Observer location, feet			C B E		
X	Y	Z	90^0 Max cp	Realistic	Constant
20	0	4.5	367	64	422
20	30	4.5	387	109	497
20	60	4.5	395	198	595
20	90	4.5	374	414	722
20	120	4.5	331	879	879
20	150	4.5	309	26	313
20	180	4.5	333	39	359
20	210	4.5	357	64	416
20	240	4.5	378	109	491
20	270	4.5	385	198	588
20	300	4.5	364	414	715
20	330	4.5	321	879	872
20	360	4.5	298	26	306
20	390	4.5	322	39	351

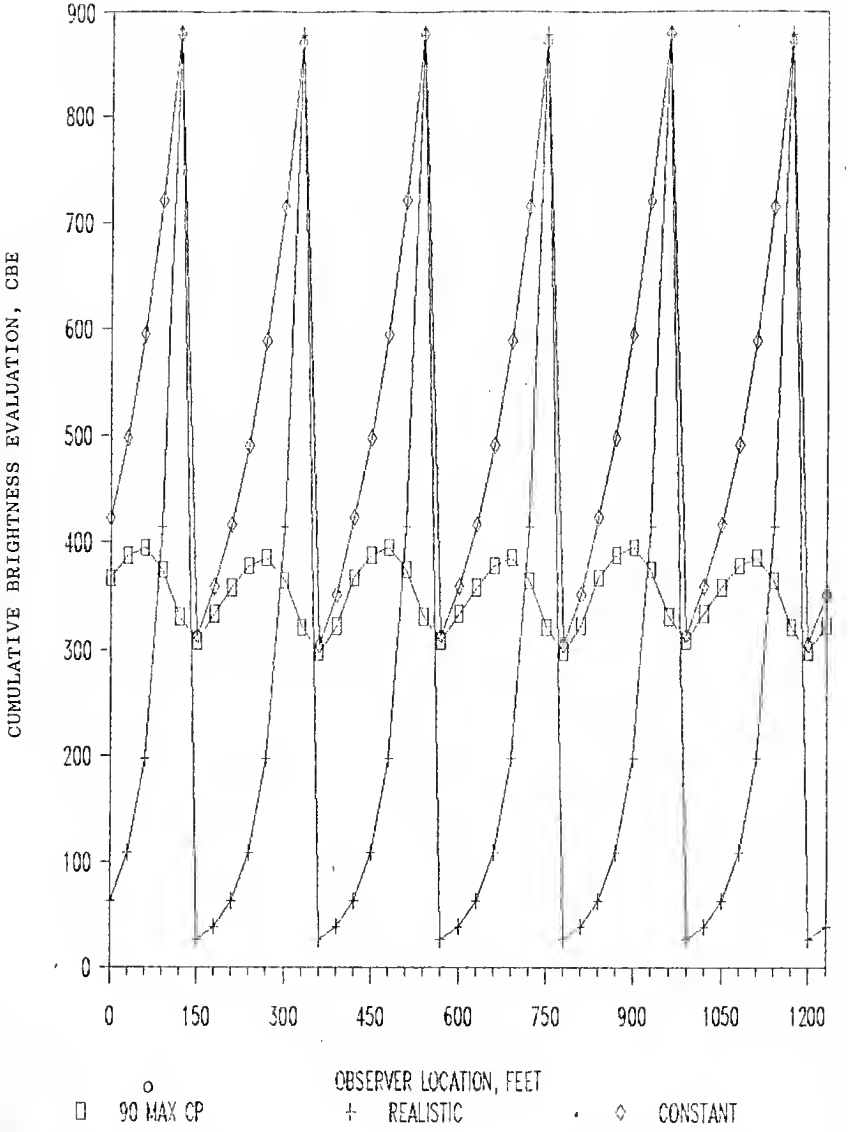

Figure 9 : CBE vs. observer location

Table 4 : CBE summary for the three types of luminaire.

	Luminaire type		
	90^{0} Max cp	Realistic	Constant
Area under curve (CBE*ft) (Distance from 0 ft to 420 ft)	149,000	104,000	228,000
Average CBE per foot	356	248	543
MaxCBE	395	879	879
MinCBE	298	26	306
MaxCBE/MinCBE	1.3	33.8	2.9
MaxCBE-MinCBE	97	823	573
(MaxCBE+MinCBE)/2	346	453	592

(area = 228,000).

If the maximum crest determines the system with the most glare, then the observers will find the real luminaire and the constant luminance systems essentially equal, and the 90^0 max candle power system will be the most comfortable. If the area under the curve is the key factor, then the observers will find the real luminaire most comfortable, the 90^0 maximum candle power next and the constant luminance system the least comfortable. If the ratio of maximum to minimum or the difference between maximum and minimum value is the key factor, then the observers will find the 90^0 maximum candle power system most comfortable, the constant luminance next and the real luminaire least comfortable. If the average of maximum and minimum value is the key factor, then the 90^0 maximum candle power system will be most comfortable, the real luminaire next and the constant luminance least comfortable. If the assumptions mentioned above don't determine the system, some other combination of the above factors determines the comfort.

<u>Determination of the Filter Gradient</u> With an assumed windshield cutoff angle of 20^0, luminaire candlepower need be considered only for a vertical angle of 70^0 and above. The horizontal angle depends on the location of the luminaire relative to the lane in which the driver is driving. In this case the angle is consistently 90^0.

The luminaire luminance is :

$$L = \frac{CP}{A} (LLF) (pi)$$

Where,

L = Luminaire luminance, foot-lamberts

CP = Candlepower of source, candelas

A = Luminous area, square ft.

LLF = Lightloss factor, dimensionless

pi = Constant, 3.14159

In this case, we assume that the lightloss factor for the three luminaires is the same and is equal to 1. The luminous area for a cobrahead luminaire remains constant at 0.347 ft^2 from luminance angles 70^0 to 90^0 (based on the radius of the cobrahead luminaire of 0.47 foot, the luminous area is $1/2 \times 3.14 \times (0.47)^2 = 0.347\ ft^2$). The calculation of luminance vs luminance angle is shown in Table 5. The design of the filter gradient for the experiment is shown in Table 6. This filter gradient gave the necessary luminaire track with luminance values varying as a function of driver viewing angle, for the position of the luminaire and driver considered.

Figure 10 shows the design of the occluder with filters mounted on it to obtain a varying output. To obtain a constant light output, the occluder was used without the filters.

<u>Realistic Luminance</u> This is a luminaire being produced

Table 5 : Calculation of luminance vs luminance angle.

Luminance angle, degrees	Candlepower, candela	Luminance, foot-lamberts	Percentage of maximum luminance, %
70	3,718	34,153	100.0
72.5	3,335	30,635	89.7
75	2,251	20,678	60.5
77.5	1,544	14,183	41.5
80	1,040	9,553	28.0
82.5	739	6,788	20.0
85	520	4,777	14.0
87.5	386	3,546	10.4

Table 6 : Design of the filter gradient. See Figure 10. Each filter covered 4°.

Filter position	Center of luminance angle, degrees	Observer angle, degrees	Filter* Density	Filter* Transmittance, %
1	72	18	No filter	100
2	76	14	.1	80
3	80	10	.3	50
4	84	6	.6	25
5	88	2	.3+1.0	5

*Kodak Wratten Gelatin Filter

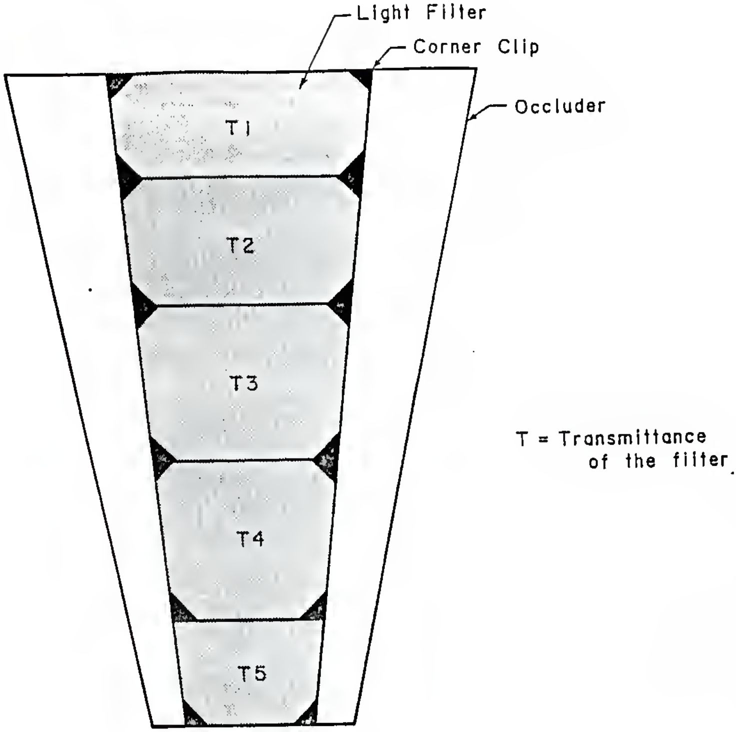

Figure 10: Design of occluder with filter

today. The maximum candlepower is produced at 72^0. The candlepower at 90^0 is 5% of the maximum. The variac controlling the maximum candlepower was set to produce a luminance, through the tempered glass and the two clear plastic disks, of 108,000 cd/m^2 or 31,400 foot lamberts. On the occluder, there were five areas of different transmittance. Each filter covered the same size area and was centered according to Table 6.

Each filter spanned 4^0. The one centered on 76^0 covered the area from 74^0 to 78^0 of luminaire angle, which is 12^0 to 16^0 of observer angle. In terms of the disk, the occluder had no filter at the top (widest area of the wedge-shaped slot).

<u>90^0 Maximum Candlepower</u> This is a luminaire not being produced today, since it is the opposite of what is normally manufactured. It is the exact reverse of the Realistic Luminaire. The no filter area occupied the 4^0 at the bottom of the slot; the 5% filter was at the top of the slot. The variac was set in the exactly the same position to produce 108,000 cd/m^2 or 31,400 foot lamberts at the 88^0 luminaire angle.

<u>Constant Luminance</u> This type of luminaire exists; it would be a ball globe or diffusing sphere with the light source mounted at the center. It has the same luminance regardless of the angle of view. In this case the occluder had no filters. The variac was set so that the luminance of

the area viewed through the two disks was 97,000 cd/m^2 or 28,300 foot lamberts. This made the peak of the calculated CBE (Cumulative Brightness Evaluation) values identical to the Realistic Luminance.

Design of Road Scene

The road scene was divided into 4 distinct areas (Figure 11). The sky is from the horizon (hub center) to the top. The roadway starts from the hub center and proceeds to widen as it comes closer to the vehicle. The pavement marker come from one-third of the way over to the left. The landscape is below the horizon and on each side of the roadway. The scene was illuminated by a incandescent light source which produced a 2.5 cd/m^2 luminance on the road scene. The reflectances were varied in each area using different colors of paint. The reflectance of each area in the two levels of scene is shown in Table 7.

Pupil Size Index (PSI)

When the subject has a continuous light pulse in the subjective determination of the BCD adjustment, theoretically the fluctuation of pupil size becomes a saw tooth wave pattern with the amplitude between the maximum and minimum dependent on the difference in brightness between the spot and the background. The PSI was determined by using three cycles of light pulse at the subject's BCD threshold. The first is one cycle before the BCD, the second is at the BCD threshold, and the third is one cycle

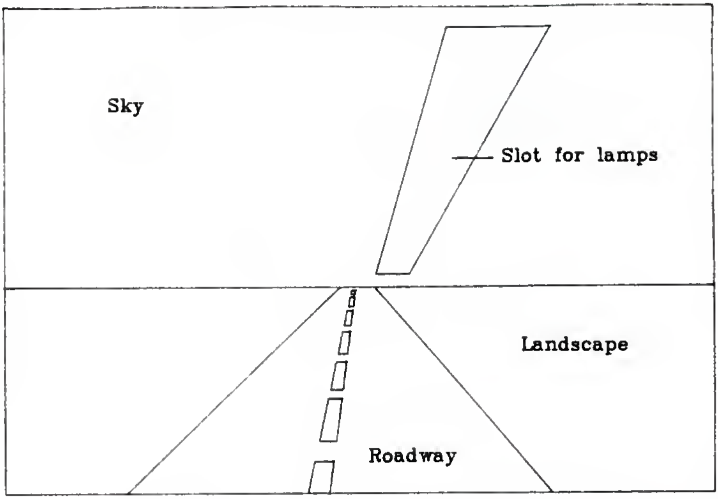

Figure 11 : Design of the road scene. See Table 7.

Table 7 : Scene reflectances for the two scenes. Luminance on the scene was 2.5 cd/m^2.

Scene	Sky		Roadway		Landscape	
	% ref.	cd/m^2	% ref.	cd/m^2	% ref.	cd/m^2
A	25	.625	40	1.000	5	.125
B	25	.625	80	2.000	5	.125

after the BCD (Figure 12). The index was suggested by Dr. Glenn Fry.

$$PSI = (MAX - MIN) / AVG$$

where,

MAX = Maximum pupil diameters during the three cycles, mm

MIN = Mainimum pupil diameters during the three cycles, mm

AVG = (MAX+MIN)/2, mm

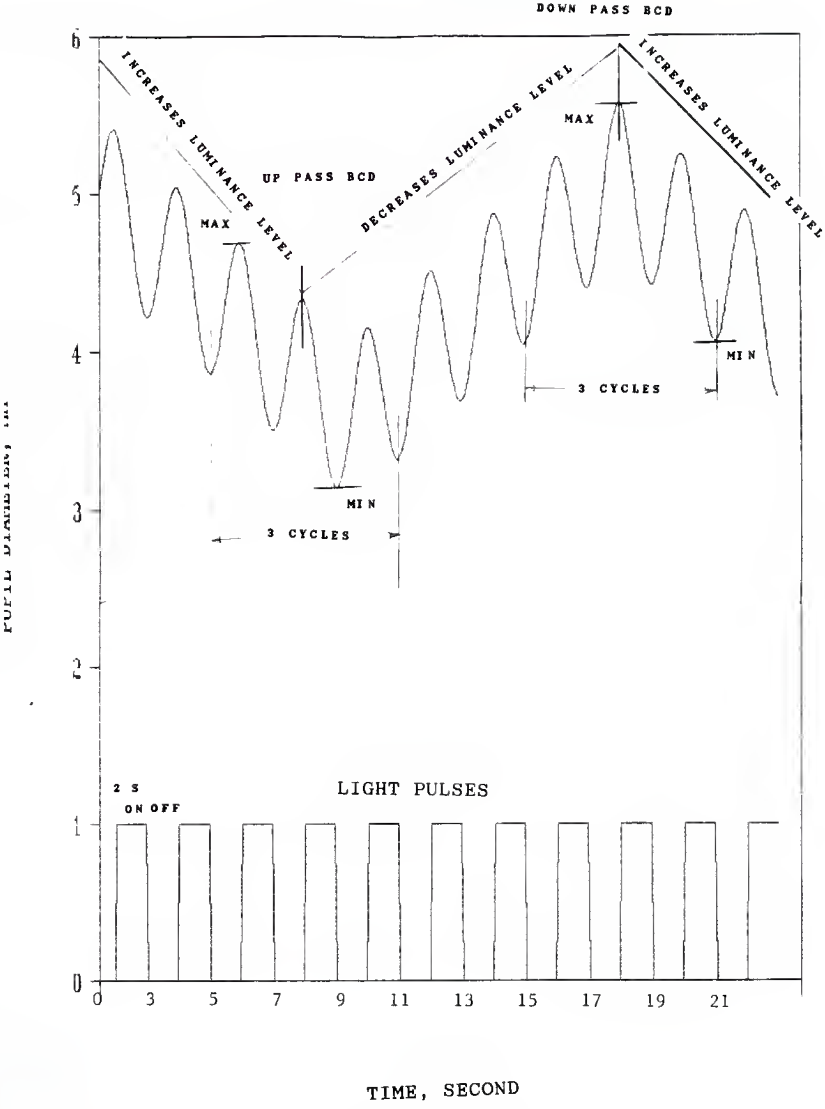

Figure 12 : Concept of PSI.

EXPERIMENT 1

Task

Experiment 1, a screening procedure, took place in the Visual Simulation room, Durland 126. There was a wide viewing screen (48 by 48 inch) with a white matte paint finish (approximate 80% reflectance). The screen (Figure 13) was lighted approximately uniformly by the light from a 15 watt incandescent light bulb to a level of approximately 32 cd/m^2. In the center was a 15 mm hole, the "spot", covered by a piece of milk glass with a frosted incandescent lamp behind it; the lamp was controlled by a variac. A control relay device transferred the pulse pattern signal from the computer to the lamp behind the screen. An IBM AT computer was used to send the pulse pattern signal to the control relay device (Figure 14).

The subject, controlling the variac, sat 1 meter from the viewing screen. The chin of the subject rested on the chin rest. There was a control device in the electrical circuit between the variac and the lamp which produced a pulse pattern with an interval of 2 seconds off and 2 seconds on. The same pulse pattern was repeated until the subject found the BCD point. With the variac initially in the "low" or "high" position, the subject adjusted the brightness of the pulse train level upward past BCD and then downward past BCD and then upward to reach and stop at BCD. The fluorescent room lights in the ceiling were turned off

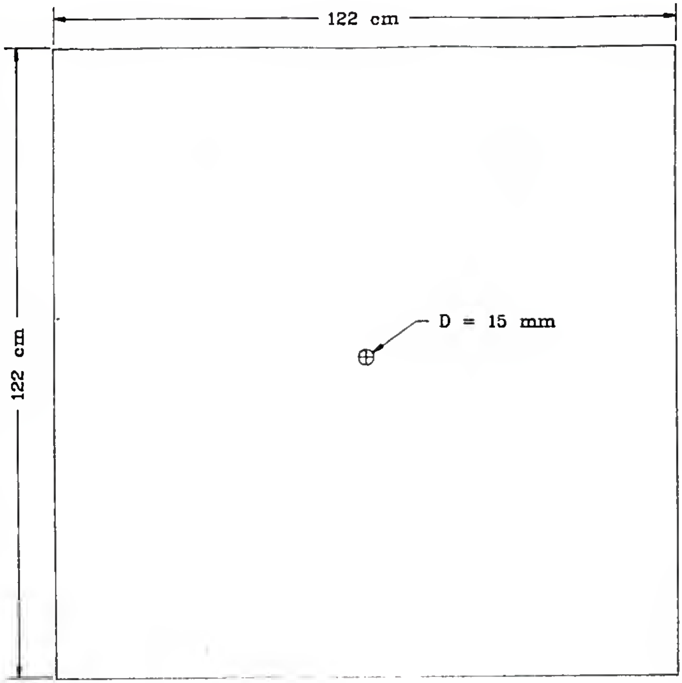

Figure 13 : Design of the viewing screen

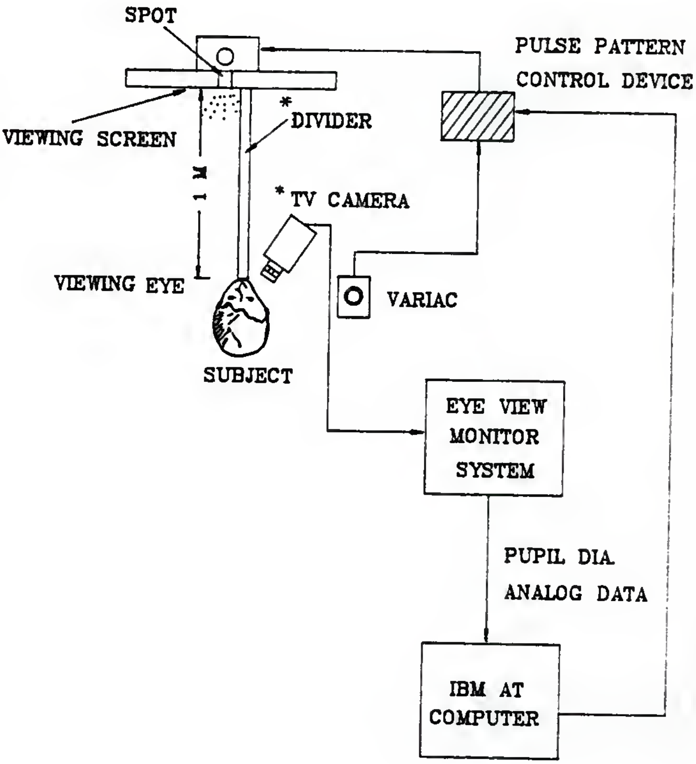

Figure14 : Eye monitor and device control system For experiment 1 and 3. The divider and TV camera were used in experiment 3.

during the experiment.

Subjects

The subject could not wear contact lenses or eye glasses during the experiment. Their vision had to be approximately 20 - 20 without correction.

The subjects were recruited from IE 625 and IE 373 courses or by an ad in the university newspaper. The subjects were offered a payment of $5 or 10 extra credit points in one of the courses IE 625 and IE 373. There were 52 subjects in this experiment (19 females and 33 males). The age of the subjects varied from 19 years to 28 years with a mean age of 22 years.

Procedure and Experimental Design

When the subject reported to the laboratory, the subject read a description of the experiment (Figure 15), indicated willingness to participate. The subject then was given a detailed instruction sheet (Figure 16) for the specific task.

The initial orientation of the variac was fixed and the variac dial was marked. Figure 17 gives the initial orientation of variac for high and low luminances. With the variac in either the "low" or "high" position, the subject adjusted the pulse train luminance level upward past BCD and then downward past BCD and then upward to reach and stop at BCD. The subject was given 5 practice trials. Then the subject had 5 minutes rest before starting the 6 criterion

Experiment 1 : BCD study informed consent statement

1. I,______________________________________, volunteer to participate in a project in connection with research studies to be conducted by Kansas State University.

2. I fully understand that the purpose of the study as outlined on the orientation statement attached to this sheet.

3. I also understand that my performance as an individual will be treated as research data and will in no way be associated with me for any other than identification purposes, thereby assuring anonymity of my performance and responses.

4. I understand that I am a volunteer for this research and that I may decline to participate with no penalty. I further understand that I will be permitted to leave the test at any time and I may discontinue participation without penalty, or loss of benefits to which I am otherwise entitled.

5. I understand that I can receive a payment of five dollars or I can receive 10 extra credit points in one of the courses IE 625 , IE 541 and IE 373. If I do not complete the session, I will receive only half the pay or credits.

6. There is no compensation available from Kansas State University for injured subjects.

7. Pictures may be taken during the experiment. By agreeing to participate, I consent to your right to take pictures. Pictures may be published in professional reports or journals or shown at professional meetings.

8. A questionnaire will be used.

9. I understand that my age must be over 18 and less that 28. My vision must be approximately 20-20 without correction and I cannot wear contact lens or eyeglasses during the experiment.

10. If I have any questions regarding my rights as a test subject, injuries or emergencies resulting from my participation or any questions concerning the study, I understand that I can contact Tungshang Liu at 776-6501.

11. If I have any questions about my rights as a subject or the manner in which this research was conducted I will contact Dr. Robert Lowman, Chair, Committee on Research Involving Human Subjects, the Graduate School, KSU, Manhattan, Kansas 66506 or call (913) 532-6195.
I have read the Subject Orientation Statement, attached to this form, and signed the herein Informed Consent Statement this______ day of_________, 1989.

____
Signature

Figure 15 : Informed consent statement - experiment 1

Experiment 1 instruction sheet

BCD study - subject orientation statement

Your age must be over 18 and less than 28. Your vision must be approximately 20 -20 without correction and you must not wear contact lenses or eye glasses during the experiment.

In this experiment, you will be adjusting the luminance level to a criterion called BCD (Borderline Between Comfort and Discomfort). You will adjust the BCD using the following procedure. Locate the variac placed beside you. Turn the knob of the variac in the clockwise direction. As you rotate the knob in the clockwise direction, the luminance level will increase. Now rotate in the counter-clockwise direction. This will reduce the luminance level. You are now ready to vary the luminance level to a point between comfort and discomfort (BCD), when I ask you to do so.

First, look at the light. If the intensity of light is high, most people would say that the light is uncomfortably glaring. Now take the control and turn the light down (counter-clockwise direction) until it is at a low level. Look at the light. Most people would say that the light is comfortable i.e., no glare. If the intensity of the light is low, most people would say that the light is comfortable. Now take the control and turn the light up (clockwise direction) until it is at a high level. Look at the light.

Figure 16 : Experiment 1 instruction sheet

Most people would say that the light is uncomfortably glaring. Now, somewhere between these two extremes must be a point of change, a threshold, where the light is at the borderline between comfort and discomfort. This is what we call"BCD". This point should be such that the light is not annoying or uncomfortable. Take your own time to find the BCD point.

Before the test session, you will be given 5 practice trials. After that, you will be repeating the procedure for 6 times.

The experiment will take place in the Visual Simulation room, Durland 126. The approximate time for you to complete the experiment will be about 40 minutes. You can receive a payment of five dollars or you can receive 10 extra credit points in one of the courses IE 625 , IE 541 and IE 373. If you have any questions, please ask me. I will be glad to answer them.

Figure 16 : Experiment 1 instruction sheet (Continued)

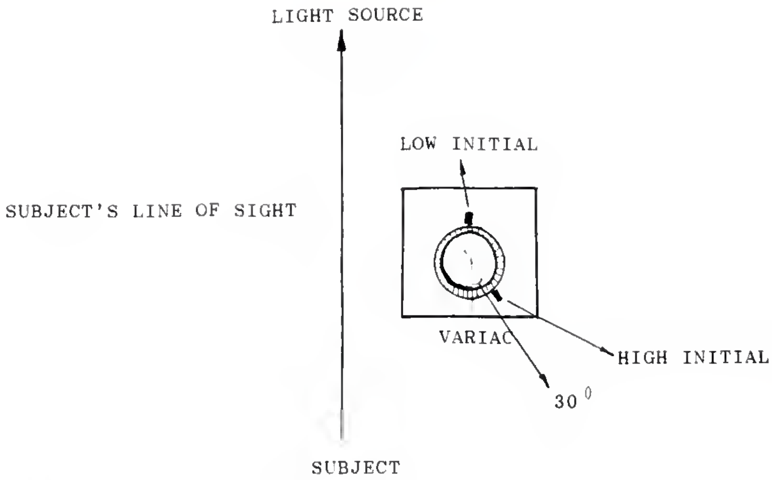

Figure 17 : Orientation of variac for low and high initial luminances

trials. There were 1 minute intervals between each trial. The experimental task was performed under the following conditions :

1. Initial luminance : low level (2,600 cd/m^2) and high level(35,000 cd/m^2).

2. Experience : this was divided into Practice (trials 2 to 5) and Criterion trials (from trial 6 to trial 11). Trial 1 was recorded but not used.

There were two initial luminances. Each of the 52 subjects viewed the two conditions in a different alternate order (Appendix 1). The criterion was the subject adjusted BCD. The independent variables were : (1) two initial luminances and (2) two levels of experience. The analysis model used a factorial design. The approximate time for the subject to complete the experiment was 40 minutes.

Measurements and Instrumentation

The subject adjusted BCD (in volts) was recorded and calibrated in cd/m^2 (Figure 18). The time to reach the BCD point also was obtained. The data collecting form is shown in Figure 19.

Results

Most of the subjects were not quite familiar with the adjustment procedure in the first trial so the time to reach the BCD was not reasonable. So we eliminated the data of the first trial, i.e., initial trials were from trial 2 to trial 5 and criterion trials were from trial 6 to trial 11.

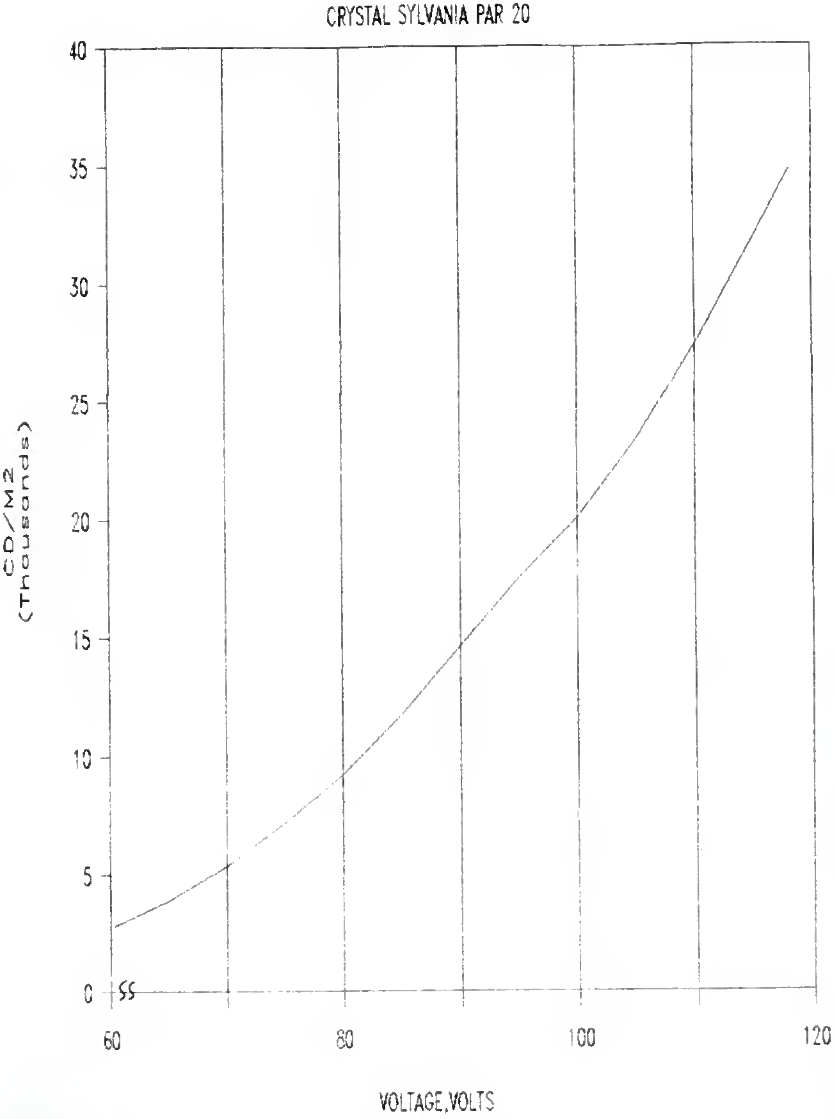

Figure 18 : Luminance calibration chart-experiment 1

BCD study data sheet

Subject :   Date :

Seq	Experience, prac/cri	Init. lum., low/high	Time, seconds	BCD adj. volts	cd/m^2
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					

Figure 19 : BCD study data sheet - experiment 1

trial 5 and criterion trials were from trial 6 to trial 11. Subject 32 was so glare sensitive that even the minimum luminance level (2,600 cd/m^2) was still above her BCD point. The data of this subject was deleted from the data set. So one subject was removed. The overall mean BCD is 12,700 cd/m^2 with the maximum 34,700 cd/m^2 and the minimum 2,660 cd/m^2. The overall mean adjusting time is 46 seconds with the maximum 406 seconds and minimum 8 seconds. The raw data of the subject's adjusted BCD and adjusting time are shown in Appendix 1.

<u>Main Effects - BCD</u> The General Linear Model procedure (Table 8) showed that there was a statistically significant effect of initial luminance (Table 9). The subject effect also was statistically significant. Experience was not significant. There were significant interactions of subject by initial luminance and subject by experience. The interaction of initial luminance by experience was not significant.

Mean BCD vs trial for high and low initial luminance (Figure 20) was plotted. It shows that the BCD value was higher in the high initial luminance in most trials. With the quadratic regression analysis (Table 10), the equation was :

BCD = 13354 - 134 (Trial) + 4 $(\text{Trial})^2$. The coefficient of determination was 0.1 %. The average BCD value in each trial and the least square line were plotted against the

Table 8 : Analysis of variance of BCD - experiment 1.

Source	df	ANOVA MS	F-value	Pr>F
(A)Subject	50	32,394,000	55.86	0.0001**
(B)Initial lum.	1	40,001,000	6.90	0.0091*
(C)Experience	1	105,020,000	1.81	0.1794
(A)*(B)	50	24,735,000	3.15	0.0001**
(A)*(C)	50	132,000	4.27	0.0001**
(B)*(C)	1	18,252,000	0.02	0.8802
(A)*(B)*(C)	50	8,239,000	1.42	0.0405*
Error	305	5,799,000		
Total	508			

* Significant at p<.05

** Significant at p<.001

Table 9 : BCD means by initial luminance (N= 510).

Initial luminance	Means (cd/m^2)	Grouping
High level	12,960	A
Low level	12,400	B

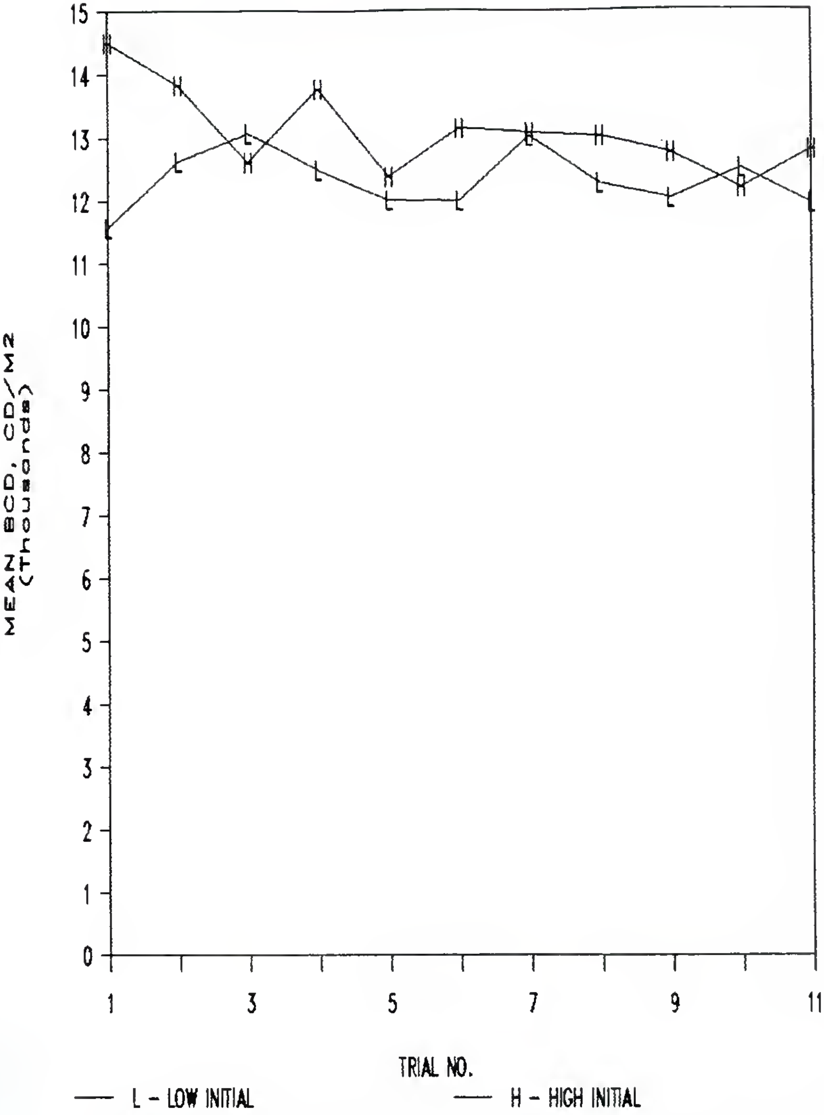

Figure 20 : Mean BCD vs. trial for high and low initial luminances. Trial 1 is omitted from calculations.

Table 10 : Regression for BCD and trial.

Dependent variable : BCD $R^2 = 0.001$

	df	Sum of square	Mean square	F	Pr >F
Model	2	33,795,000	16,898,000	0.385	0.6805
Error	557	24,437,925,000	43,874,000		
Total	559	24,471,720,000			

	Coefficient	T test for H0: parameter=0	Prob>¦T¦
Intercept	13,180	12.9	0.0001**
Trial	-79	-0.2	0.8397
Trial ^{2}	0.1	0.003	0.9973

** Significant at p<.001

trial number (Figure 21). It shows that the overall the mean BCD value didn't fluctuate much. The mean BCD value fluctuates slightly at the beginning and remains steady after trial 9.

Main Effects - Adjusting Time The General Linear Model procedure (Table 11) showed that subjects and experience were statistically significant (Table 12). Initial luminance was not significant. There was a significant interaction of subject by experience. The interaction of initial luminance by experience and subject by initial luminance were not significant.

Mean time vs trial for high and low initial luminance (Figure 22) was plotted. It shows that time for high and low initial luminance intersect. With the quadratic regression analysis (Table 10), the equation was :
Time = 59.5 - 2.7 (Trial) + 0.1 $(\text{Trial})^2$. The coefficient of determination was 2 %. The average adjusting time in each trial and the least square line were plotted against the trial number (Figure 23). It shows that the trend of the adjusting decreases from trial 2 to trial 11.

Correlation of BCD and Adjusting Time The coefficient of determination of BCD vs the adjusting time (Table 14) was $(-.09)^2 = .0081 = .8\%$; this is statistically significant but practically insignificant. The correlation of mean time and the standard deviation of BCD was not significant (Table 14).

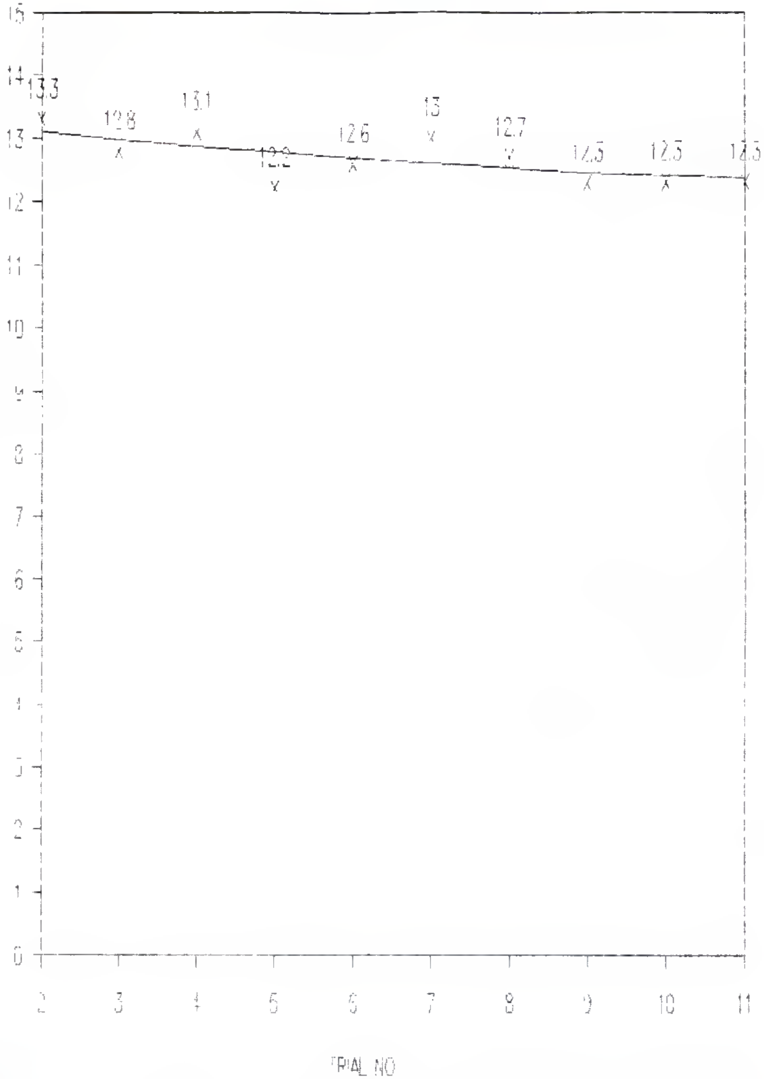

Figure 21 : Mean BCD vs. trial no and the least square line.

Table 11 : Analysis of variance of time - experiment 1.

Source	df	ANOVA MS	F-value	Pr>F
(A)Subject	50	7,964	21.82	0.0001**
(B)Initial lum.	1	33	0.09	0.7651
(C)Experience	1	9,062	24.83	0.0001**
(A)*(B)	50	204	0.56	0.9931
(A)*(C)	50	679	1.86	0.0008**
(B)*(C)	1	642	1.76	0.1856
(A)*(B)*(C)	50	118	0.32	1.0000
Error	305	365		
Total	508			

* Significant at $p<.05$

** Significant at $p<.001$

Table 12 : Time means by experience (N=510).

Experience	Trial	Means,s	Grouping
Criterion	6-11	42	A
Practice	2-5	51	B

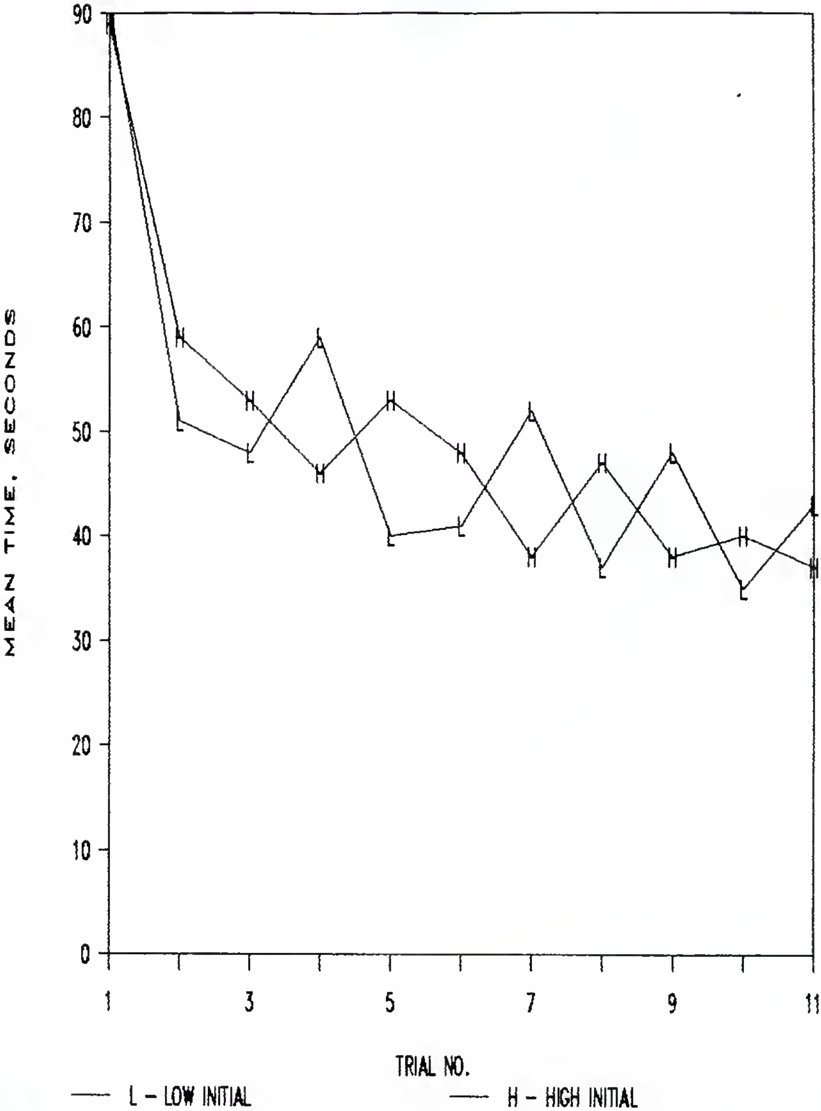

Figure 22 : Mean time vs. trial for high and low initial luminances. Trial 1 is omitted from calculations.

Table 13 : Regression for time and trial.

Dependent variable : Time $R^2 = 0.02$

	df	Sum of square	Mean square	F	Pr >F
Model	2	78,410	39,200	27.342	0.0001**
Error	557	800,050	1,430		
Total	559	878,460			

	Coefficient	T test for H0: parameter=0	Prob>¦T¦
Intercept	86.5	14.9	0.0001**
Trial	-11.2	-5.0	0.0001**
$Trial^2$	0.7	3.6	0.0003**

** Significant at p<.001

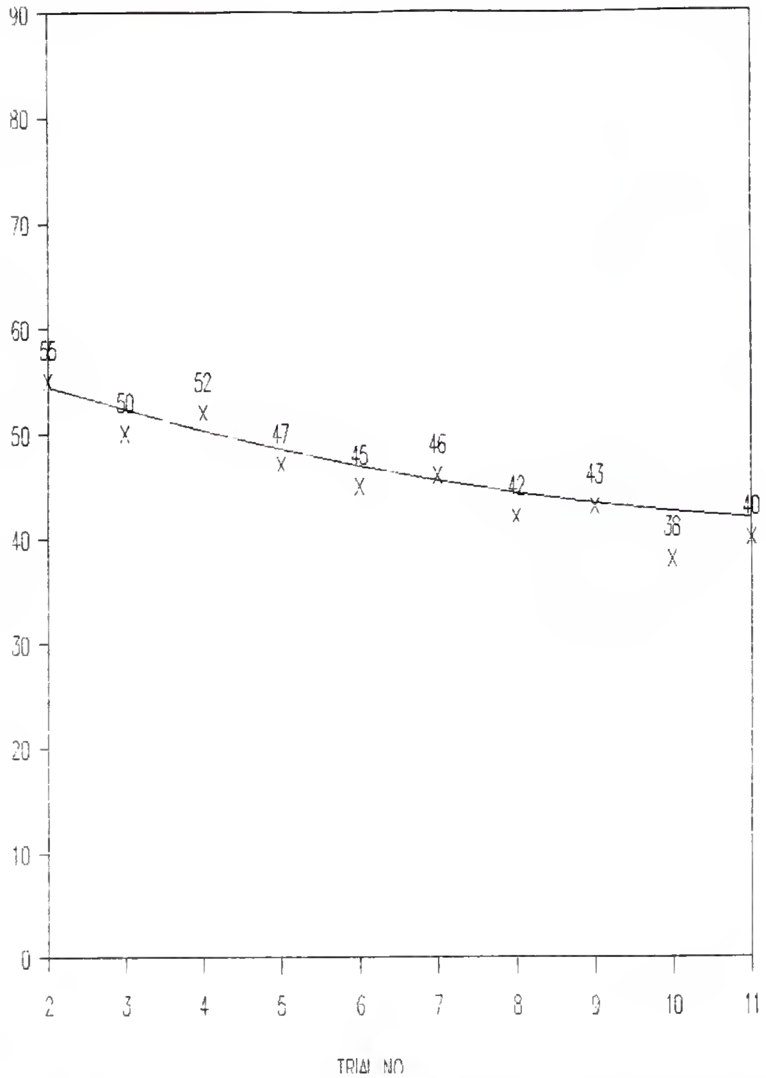

Figure 23 : Mean time vs. trial no and the least square line.

Table 14 : Correlation of BCD and adjusting time in experiment 1.

Time vs BCD

Pearson Correlation Coefficients (R)	-.09
Probability >¦R¦ under RHO : R=0	0.04450 *
Number of Observations	510

Mean Time vs Standard Deviation of BCD

Pearson Correlation Coefficients (R)	.09
Probability >¦R¦ under RHO : R=0	0.52550
Number of Observations	51

* Significant at $p<.05$

Subject Selection We assumed that the sample of subjects was a normal distribution. The criteria to determine a qualified subject for experiment 2 were : (1) capability to recognize BCD consistently and (2) have a "non-extreme" BCD.

Consistency The qualified subject should be able to reproduce the BCD setting consistently. The standard deviation was used as a measurement to determine the consistency of the subject. The subject's standard deviation (from trial 2 to trial 11) ranged from 400 cd/m^2 for subject 47 to 6,610 cd/m^2 for subject 12 (Table 15). The histogram of standard deviations is shown in Figure 24. Each subject was given a score with highest points (51) for the largest standard deviation to lowest points (1) for the smallest standard deviation.

Determination of Average Observer We specified that a qualified subject should fall into the middle 80 percentile of the population; that is between $\pm$ 1.28 Z. The observed Z-value is from -0.01 standard deviation for subject 25 to 2.46 standard deviation for subject 12 (Table 16).

A score was given to each subject, based on the absolute Z probability, from 51 points for the largest absolute Z probability to 1 point for the smallest absolute Z probability. We eliminated the 10 subjects with an absolute Z probability greater than 0.4. That is,i.e.

Table 15 : Mean, standard deviation, coefficient of variation and consistency ranking - experiment 1.

Subject	Mean BCD, cd/m2	Standard deviation, cd/m2	Coefficient of variation	Consistency rank
1	13,200	2,530	0.19	39
2	12,800	1,520	0.12	24
3	17,200	2,700	0.16	42
4	8,900	3,550	0.40	47
5	4,400	540	0.12	5
6	10,900	2,860	0.26	43
7	12,100	1,210	0.10	17
8	4,900	580	0.12	6
9	14,200	1,300	0.09	21
10	21,300	2,160	0.10	30
11	10,800	1,370	0.13	22
12	26,900	6,610	0.25	51
13	13,100	3,700	0.28	48
14	8,100	2,300	0.28	33
15	13,400	2,270	0.17	32
16	4,900	620	0.13	8
17	25,800	1,240	0.05	18
18	14,400	870	0.06	11
19	16,800	3,280	0.20	45
20	15,100	4,000	0.26	49
21	17,500	2,600	0.15	40
22	4,700	1,270	0.27	20
23	12,700	2,370	0.19	35
24	11,400	2,520	0.22	37
25	12,500	2,300	0.18	34
26	20,100	2,620	0.13	41
27	21,000	2,520	0.12	38
28	6,500	500	0.08	3
29	10,600	2,500	0.24	36
30	17,100	890	0.05	12

Table 15 : Mean, standard deviation, coefficient of variation and consistency ranking - experiment 1.(Continued)

Subject	Mean BCD, cd/m2	Standard deviation, cd/m2	Coefficient of variation	Consistency rank
31	15,200	480	0.03	2
33	7,600	1,020	0.13	13
34	21,400	4,490	0.21	50
35	23,200	3,400	0.15	46
36	3,900	770	0.20	10
37	6,300	1,250	0.20	19
38	13,000	2,210	0.17	31
39	10,900	1,600	0.15	26
40	12,200	3,230	0.26	44
41	6,400	670	0.10	9
42	7,300	610	0.08	7
43	16,100	1,960	0.12	28
44	4,300	1,500	0.35	23
45	18,600	1,050	0.06	16
46	11,000	1,540	0.14	25
47	5,000	400	0.08	1
48	17,400	1,740	0.10	27
49	10,000	1,030	0.10	14
50	5,500	510	0.09	4
51	5,500	2,000	0.36	29
52	16,400	1,040	0.06	15
Average	12,600	1,900	0.16	
Standard Deviation	5,800	1,200	0.08	

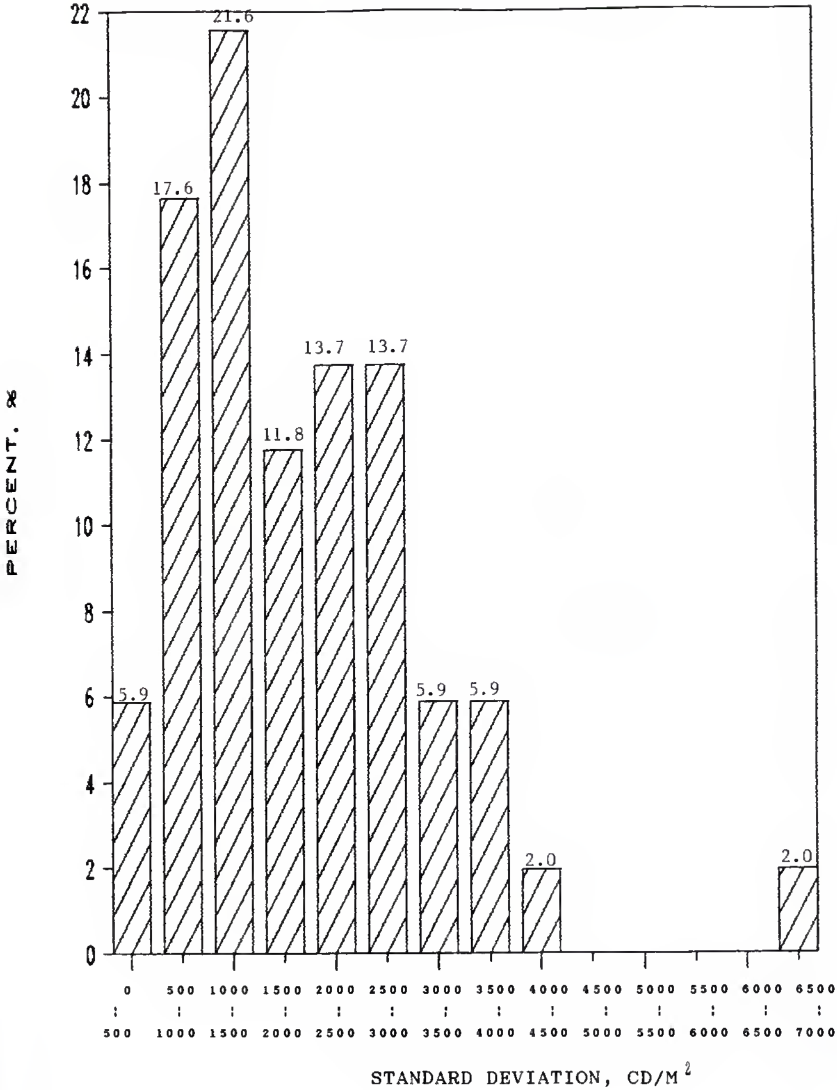

Figure 24 : Histogram of standard deviation

Table 16 : Average observer ranking - experiment 1.

Sub.	Z Value	Absolute Z probability	Average observer rank
1	0.11	0.04	8
2	0.04	0.02	3
3	0.80	0.29	27
4	-0.63	0.24	22
5	-1.40	0.42	*
6	-0.28	0.11	12
7	-0.08	0.03	5
8	-1.31	0.40	40
9	0.28	0.11	11
10	1.50	0.43	*
11	-0.30	0.12	14
12	2.46	0.49	*
13	0.09	0.04	7
14	-0.76	0.28	25
15	0.14	0.16	17
16	-1.31	0.40	41
17	2.27	0.49	*
18	0.32	0.13	15
19	0.73	0.27	24
20	0.44	0.17	18
21	0.85	0.30	29
22	-1.35	0.41	*
23	0.02	0.01	2
24	-0.20	0.08	9
25	-0.01	0.00	1
26	1.29	0.40	38
27	1.45	0.43	*
28	-1.04	0.35	33
29	-0.34	0.13	16
30	0.78	0.28	26
31	0.45	0.17	20
33	-0.85	0.30	30
34	1.51	0.43	*
35	1.82	0.47	*

Table 16 : Average observer ranking - experiment 1. (Continued)

Sub.	Z Value	Absolute Z probability	Average observer rank
36	-1.48	0.43	*
37	-1.07	0.36	35
38	0.08	0.03	6
39	-0.28	0.11	13
40	-0.06	0.02	4
41	-1.06	0.36	34
42	-0.90	0.32	31
43	0.61	0.23	21
44	-1.41	0.42	*
45	1.03	0.35	32
46	-0.27	0.11	10
47	-1.29	0.40	39
48	0.83	0.30	28
49	-0.44	0.17	19
50	-1.21	0.39	37
51	-1.21	0.39	36
52	0.66	0.25	23

* Eliminated for being outside the middle 80 percentile

subject 5, 10, 12, 17, 22, 27, 34, 35, 36 and 44.

Selection of the Experiment 2 Subjects Each subject has a score for each criterion. Ten subjects were eliminated for being outside the middle 80 percentile. Then we added the two ranks together. We choose the 10 subjects with the smallest total rank (Table 17). The ten preferred subjects for experiment 2 were subject 31, 7, 18, 2, 9, 49, 25, 46, 11 and 28. The five alternates were subject 23, 38, 30, 52 and 42. The subjects with an underline are the 10 subjects actually used in Experiment 2.

Discussion

Initial Luminance Effect The initial luminance effect was found significant for BCD (Table 8) but not for time.

From Table 9, mean BCD for high initial luminance was 12,960 cd/m^2 and for low initial luminance was 12,400 cd/m^2; the 560cd/m^2 is about 4%. Thus initial luminance affects the value of subject adjusting BCD. With a higher adaption level at the beginning, the subject will become more glare tolerant and tend to adjust to a higher BCD.

Experience Effect The experience effect was significant for time (Table 11) but was not significant for BCD.

From Table 12, the adjusting time for trials 2-5 was 51 seconds and for trial 6-11 was 42 seconds. Subjects can determine the BCD point more quickly with experience.

Subjects Selection The criteria for qualified subjects

Table 17 : Subjects selection priority - experiment 1.

Sub.	Consistency rank	Average obs. rank	Total rank	Selection priority
1	39	8	23.5	16
2	24	3	13.5	3
3	42	27	34.5	25
4	47	22	34.5	25
5	5	*	*	*
6	43	12	27.5	21
7	17	5	11.0	1
8	6	40	23.0	15
9	21	11	16.0	4
10	30	*	*	*
11	22	14	18.0	7
12	51	*	*	*
13	48	7	27.5	21
14	33	25	29.0	22
15	32	17	24.5	18
16	8	41	24.5	18
17	18	*	*	*
18	11	15	13.0	2
19	45	24	34.5	25
20	49	18	33.5	24
21	40	29	34.5	25
22	20	*	*	*
23	35	2	18.5	8
24	37	9	23.0	14
25	34	1	17.5	6
26	41	38	39.5	26
27	38	*	*	*
28	3	33	18.0	7
29	36	16	26.0	19
30	12	26	19.0	9
31	2	20	11.0	1
33	13	30	21.5	13
34	50	*	*	*
35	46	*	*	*

Table 17 : Subjects selection priority-experiment 1. (Continued)

Sub.	Consistency rank	Average obs. rank	Total rank	Selection priority
36	10	*	*	*
37	19	35	27.0	20
38	31	6	18.5	8
39	26	13	19.5	10
40	44	4	24.0	17
41	9	34	21.5	13
42	7	31	19.0	9
43	28	21	24.5	18
44	23	*	*	*
45	16	32	24.0	17
46	25	10	17.5	6
47	1	39	20.0	11
48	27	28	27.5	21
49	14	19	16.5	5
50	4	37	20.5	12
51	29	36	32.5	23
52	15	23	19.0	9

* Eliminated for being outside the middle 80 percentile

were based on the assumption that the sample was a normal distribution. Subject with a more consistent BCD not only knew the definition of BCD more clearly but also were serious about the experiment.

The reason for specifying that a qualified subject should fall into the middle 80 percentile of the population is that : (1) for the lower bound of the distribution, we avoided the subjects who were so glare sensitive that they could not discern the degree of comfortable glare, (2) for the upper bound of the distribution, we avoided the subjects who were so glare tolerant that they could not distinguish the discomfort glare among the experimental conditions.

EXPERIMENT 2

Task

The experiment took place in the Visual Simulation room, Durland 126, using the dynamic simulator.

Subjects

Among the ten most qualified subjects in experiment 1, eight subjects participated in experiment 2, i.e., subject 31, 7, 18, 49, 25, 46, 28 and 11. We used two alternates, i.e., subject 23 and 38. The ten subjects' BCD in experiment 1 ranged from 6,800 cd/m^2 to 20,100 cd/m^2 and standard deviation ranged from 500 cd/m^2 for subject 28 to 2,900 cd/m^2 for subject 7. Each subject was paid $ 20. There were two more volunteers (subject 3 and 45 in experiment 1) participating in the relative rating procedure.

Procedure and Experimental Design

When the subject reported to the laboratory, the subject read a description of the experiment (Figure 25) and indicated willingness to participate. The subject then was given a detailed instruction sheet (Figure 26) for the specific task.

First, the subject viewed the 18 conditions in a random order using the BCD adjustment. Then, on the same day, the subject viewed the 18 conditions in a different random order using the Glaremark rating. Then the subject repeated the 18 conditions in a different order on another day ,i.e., 2

Informed consent statement
Simulator experiment - experiment 2

1. I,____________________________________, volunteer to participate in a project in connection with research studies to be conducted by Kansas State University.

2. I fully understand that the purpose of the study as outlined on the orientation statement attached to this sheet.

3. I also understand that my performance as an individual will be treated as research data and will in no way be associated with me for any other than identification purposes, thereby assuring anonymity of my performance and responses.

4. I understand that I am a volunteer for this research and that I may decline to participate with no penalty. I further understand that I will be permitted to leave the test at any time and I may discontinue participation without penalty, or loss of benefits to which I am otherwise entitled.

5. I understand that I can receive a payment of twenty dollars. If I do not complete the session, I will receive only half the pay.

6. There is no compensation available from Kansas State University for injured subjects.

7. Pictures may be taken during the experiment. By agreeing to participate, I consent to your right to take pictures. Pictures may be published in professional reports or journals or shown at professional meetings.

8. A questionnaire will be used.

9. I understand that my age must be over 18 and less that 28. My vision must be approximately 20-20 without correction and I cannot wear contact lens or eyeglasses during the experiment.

10. If I have any questions regarding my rights as a test subject, injuries or emergencies resulting from my participation or any questions concerning the study, I understand that I can contact Tungshang Liu at 776-6501.

11. If I have any questions about my rights as a subject or the manner in which this research was conducted I will contact Dr. Robert Lowman, Chair, Committee on Research Involving Human Subjects, the Graduate School, KSU, Manhattan, Kansas 66506 or call (913) 532-6195.

I have read the Subject Orientation Statement, attached to this form, and signed the herein Informed Consent Statement this______ day of_________, 1989.

____
Signature

Figure 25 : Informed consent statement - experiment 2

Experiment 2 instruction sheet

Simulator experiment - subject orientation statement

This simulator is designed to simulate actual dynamic roadway lighting conditions. You as a subject will be performing an experiment with this simulator.

Take a seat in the car and make yourself comfortable. The seat will be adjusted for you. Now you are ready to start. Keep your hands on the steering wheel. Look at the intersection of the roadway at the horizon on the scene as if you are driving a car. You will be driving the car under several different types of luminaries, car speeds and road scenes.

In the first part of the experiment, you will be asked to rate the glare according to the Glaremark Scale. This scale also is posted to your right in the car. Please go through this carefully.

In the second part of experiment, you will be adjusting the luminance level to a criterion called borderline between comfort and discomfort (BCD) that you had experienced in the screening process before. You will adjust the BCD using the following procedure.

Locate the transformer placed beside your seat. Turn the knob of the transformer in the clockwise direction for about 25 degrees. As you rotate the knob in the clockwise direction the luminance level will increase.

Figure 26 : Experiment 2 instruction sheet

Now rotate in the counter-clock direction. This will reduce the luminance level. You are now read to adjust the luminance level to a point BCD, when I ask you to do so.

First, take the control and increase the intensity of light to a high level (the light is uncomfortably glaring). Now take the control and turn the light down to a low level at which the light is comfortable ,i.e., no glare. Now somewhere between these two extremes must be a point of change, a threshold, where the light is at the BCD. This point should be such that the light is not annoying or uncomfortable to you, but, if it were any higher, it would be uncomfortable. Take your own time to find the BCD point.

The experiment will take place in the Visual Simulation room, Durland 126. The approximate time for you to complete the experiment will be one hour and ten minutes and you will repeat the same procedure at a different day. You can receive a payment of twenty dollars, if you complete both sessions. If you have any questions, please ask me. I will be glad to answer them.

Figure 26 : Experiment 2 instruction sheet (Continued)

replications for Glaremark rating and BCD adjustment. The different random sequences are shown in Appendix 2 and 3.

To explore the three different types of luminaire distributions more deeply, we also used the relative rating method (Strum 1973, Saaty and Kouja 1976, Hwang and Yoon 1981) in comparison of the three luminaires. The relative rating method is a pairwise comparison procedure. For each alternative, the subject (a) identified which one of a pair was preferred (gave a score of 1 to the one not preferred), and (b) gave the amount by which it was preferred with a relative rating scale (Figure 27). Because the pair could not be presented at the same time, the pairs were presented with a short time (10 seconds) interval between the items. When the sequence of the presentation to the subject was considered, there were six combinations to present pairs of luminaire types. Each subject compared the six pairs at the end of the second day's experiment.

<u>BCD and Glaremark rating</u> The task of night driving was performed in the dynamic simulator with the following 18 conditions :

1. Three different types of luminaire distributions : Realistic luminaire, 90 degree maximum candlepower and constant luminaire.
2. Two different types of road scene (Table 7).
3. Three different car speeds : 40, 50, and 60 mph.

In all there were 18 combinations of 3 luminaire

	----	10
ABSOLUTELY BETTER	----	9
	----	8
SIGNIFICANTLY BETTER	----	7
	----	6
MUCH BETTER	----	5
	----	4
SOMEWHAT BETTER	----	3
	----	2
EQUAL TO	----	1

Figure 27 : Relative rating scale - experiment 2

distributions, 2 roadway scenes and 3 car speeds. The criteria were the subject adjusted BCD and the subject's Glaremark rating (Figure 1). The model used a completely random block design (CRBD) with replication. The subject was used as a block.

Relative rating There were three different types of luminaire distributions. The ANOVA model used a 1 way classification. The eigenvalue weight was the criterion. The type of luminaire distributions was the independent variable.

Measurements and Instrumentation

There were three measurements of discomfort glare : (1) the subject adjusted BCD (in volts) was recorded and calibrated in cd/m^2 (Figure 5), (2) the rating of the glare criterion on the Glaremark scale was obtained, and (3) the relative rating of the three luminaire distributions was obtained. The data form is shown in Figure 28.

The time to complete the 18 conditions using the BCD adjustment was 40 minutes and using the Glaremark rating was 30 minutes. Each subject repeated the procedure and did a 15 minutes pairwise ranking procedure in the second's experiment, i.e., 155 minutes per subject.

Results

The overall mean BCD was 28,000 cd/m^2 with the maximum 121,000 cd/m^2 and the minimum 2,140 cd/m^2. The overall mean Glaremark was 3.9 with the maximum 9 and minimum 1. The raw

Simulator data sheet

Subject :   Date :

Type :

Seq no.	Lumin. Type	Scene	Car speed	GM/voltage	cd/m^2
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					

Figure 28 : Simulator data sheet (Glaremark and BCD) - experiment 2

data of the subject's adjusted BCD and Glaremark rating are shown in Appendix 2 and 3.

The raw data of pairwise comparison are shown in Appendix 4. The relative rating data must be pre-processed into eigenvectors before using conventional statistics. The eigenvector method converts a two-dimensional pairwise comparison matrix (A) into a one-dimensional eigenvector (w). The sum of weights in eigenvectors for a subject must be equal to 1. Actually the value in eigenvectors of each luminaire for a subject is a "weight of preference" corresponding to total of 1. Table 18 shows the matrix and eigenvector for subject 10. Subject 10 preferred 90^0 maximum candle power luminaire over constant luminance with an average rating of 3.5 (average of 2 combinations to present pairs of luminaire types), i.e., 90^0 maximum candle power vs. constant luminaire was 3.5 over 1; therefore entry $a_{1,3} = 7/2 = 3.5$. These ratings fill exactly 1/2 of the matrix. Next the matrix is completed with the reciprocals of the corresponding entries. For example, since $a_{1,3} = 7/2$, then $a_{3,1} = 2/7 = .29$. Then the eigenvector is calculated for each luminaire by a program using Lotus 1-2-3 software. In this case, the 90^0 maximum candle power luminaire has a "weight of preference" of .56 for subject 10. The eigenvector for each subject is shown in Table 19.

<u>Main Effects - BCD</u> The Analysis of Variance procedure (Table 20) showed that subject and luminaires were

Table 18 : Pairwise comparison matrix and eigenvector (w) for subject 10.

Luminaire type	Luminaire type		
	90^0 max. cp	Realistic	Constant
90^0 max CP	1.0	2.5	3.5
Realistic	.4	1.0	3.5
Constant	.29	.29	1.0
w =	.56	.32	.12

Table 19 : Luminaires eigenvector (weight) for each subject.

A high value indicates the preferred luminaire.

Seq.	Subject in Exp.1	Luminaire Type: 90^0 max. cp	Realistic	Constant
1	38	.51	.27	.22
2	25	.22	.64	.14
3	49	.51	.37	.12
4	7	.69	.20	.11
5	28	.52	.30	.18
6	31	.67	.17	.16
7	46	.75	.08	.17
8	18	.39	.29	.32
9	11	.31	.49	.20
10	23	.56	.32	.12
11	45	.45	.32	.23
12	3	.51	.23	.26
mean		.51	.30	.19

Table 20 : Analysis of variance of raw data BCD - experiment 2.

Source	df	ANOVA MS	F-value	Pr>F
(A)Subject	9	12,474,693,000	47.26	0.0001**
(B)Replication	1	150,000	0.00	0.9806
(C)Luminance	2	6,575,488,000	25.97	0.0001**
(D)Road scene	1	41,177,000	0.16	0.6870
(E)Car speed	2	75,838,000	0.30	0.7414
(B)*(C)	2	70,826,000	0.28	0.7562
(B)*(D)	1	19,047,000	0.08	0.7841
(B)*(E)	2	85,228,000	0.34	0.7145
(C)*(D)	2	6,918,000	0.03	0.9731
(C)*(E)	4	46,540,000	0.18	0.9467
(D)*(E)	2	367,828,000	1.45	0.2355
(B)*(D)*(E)	2	78,808,000	0.31	0.7328
(B)*(C)*(D)	2	24,171,000	0.10	0.9090
(B)*(C)*(E)	4	81,821,000	0.32	0.8624
(C)*(B)*(D)	4	41,751,000	0.16	0.9561
(B)*(C)*(D)*(E)	4	88,041,000	0.35	0.8456
Error	315	253,218,000		
Total	359			

* Significant at p<.05

** Significant at p<.001

statistically significant (Table 21). Replication ,car speed and road scene were not significant. There were significant interactions of subject by replication and subject by luminaire.

With the quadratic regression analysis (Table 22), the equation was :

Time, Second = 38878 - 1980 (Trial) + 66 $(Trial)^2$. The coefficient of determination was only 3 %. The average BCD in each trial and the least square line were plotted against the trial number (Figure 29). There was a little trend that the BCD value decreased as the trials increased. This indicated that the subject's eyes dark adjusted with the time in the simulator. The General Linear Model was used to reanalyzed the data (Table 23). The trial number was used as a corvariate. The results showed that the covariate (trial number) was significant. Another adjusted data analysis was done by using the data, subtracting the average BCD value from the BCD value in each trial. The results (Table 24) showed that there were no differences between the conclusions when using the raw data and adjusted data.

Main Effects - Glaremark The Analysis of Variance procedure (Table 25) showed that subjects, luminaires and replication effect were statistically significant (Table 26 and Table 27). Car speed and road scene were not significant. There were significant interactions of subject by replication and subject by luminaire.

Table 21 : BCD means by luminaire type (N=360).

Luminaire type	Means, cd/m^2	Grouping	Relative value, %
90^0 max CP	35,900	A	170
Realistic	27,000	B	130
Constant	21,200	C	100

Table 22 : Regression for BCD and trial - experiment 2.

Dependent variable : BCD $R^2 = 0.03$

	df	Sum of square	Mean square	F	Pr >F
Model	2	5,620,212,000	2,810,106,000	4.940	0.0077*
Error	305	199,102,203,000	568,863,000		
Total	352	204,722,415,000			

	Coefficient	T test for H0: parameter=0	Prob>¦T¦
Intercept	38,878	8.9	0.0001**
Trial	-1,980	-1.9	0.0589
Trial ^{2}	66	1.3	0.2117

** Significant at p<.001

** Significant at p<.05

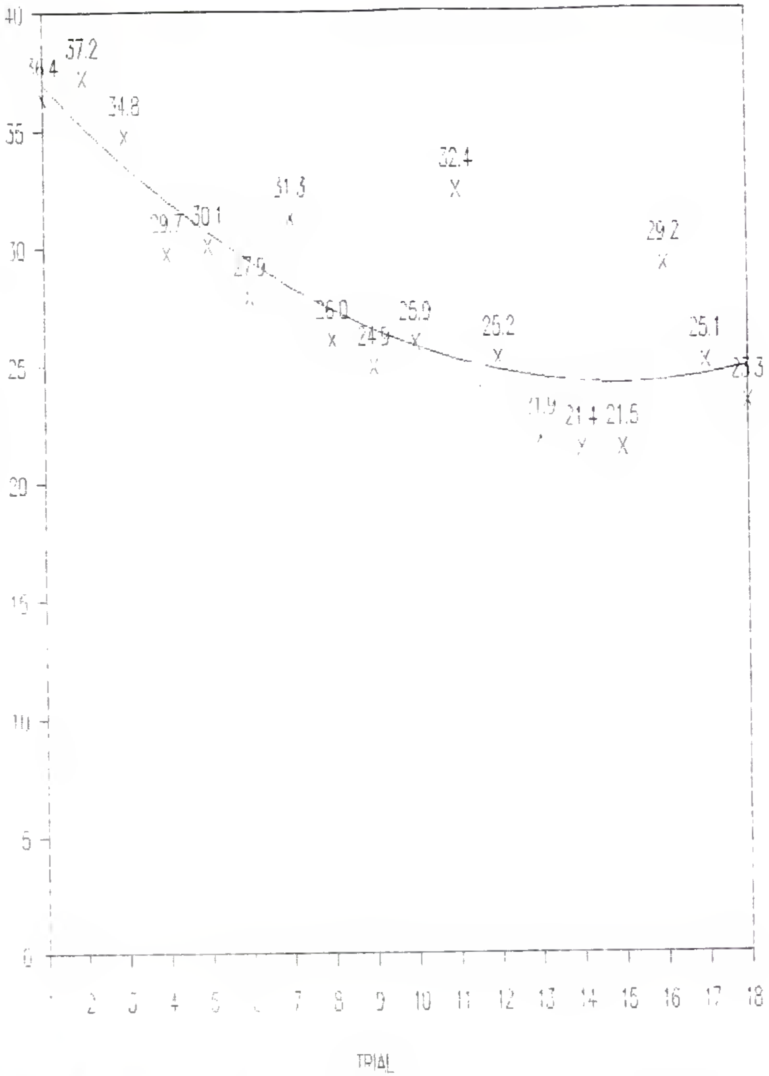

Figure 29 : Mean BCD vs. trial and the least square line.

Table 23 : Analysis of variance of raw data BCD - experiment 2. Covariate analysis.

Source	df	ANOVA MS	F-value	Pr>F
(A)Subject	9	12,474,693,000	52.56	0.0001**
(B)Replication	1	150,000	0.00	0.9800
(C)Luminance	2	5,977,497,000	25.18	0.0001**
(D)Road scene	1	65,035,000	0.27	0.6010
(E)Car speed	2	76,615,000	0.32	0.7244
(B)*(C)	2	70,362,000	0.30	0.7437
(B)*(D)	1	7,159,000	0.03	0.8622
(B)*(E)	2	84,831,000	0.36	0.6998
(C)*(D)	2	1,012,000	0.00	0.9957
(C)*(E)	4	46,731,000	0.20	0.9399
(D)*(E)	2	354,057,000	1.49	0.2266
(B)*(D)*(E)	2	107,352,000	0.45	0.6366
(B)*(C)*(D)	2	38,430,000	0.16	0.8506
(B)*(C)*(E)	4	80,901,000	0.34	0.8503
(C)*(B)*(D)	4	49,732,000	0.21	0.9330
(B)*(C)*(D)*(E)	4	75,459,000	0.32	0.8659
Sequence (Covariate)	1	5,200,920,000	21.91	0.0001**
Error	314	237,344,000		
Total	359			

* Significant at p<.05

** Significant at p<.001

Table 24 : Analysis of variance of BCD - experiment 2 (adjusted BCD).

Source	df	ANOVA MS	F-value	Pr>F
(A)Subject	9	12,474,693,000	53.87	0.0001**
(B)Replication	1	150,000	0.00	0.9797
(C)Luminance	2	5,977,497,000	25.81	0.0001**
(D)Road scene	1	11,835,000	0.05	0.8213
(E)Car speed	2	74,108,000	0.32	0.7264
(B)*(C)	2	52,331,000	0.23	0.7979
(B)*(D)	1	5,907,000	0.03	0.8732
(B)*(E)	2	116,555,000	0.50	0.6050
(C)*(D)	2	10,158,000	0.04	0.9571
(C)*(E)	4	5,081,000	0.02	0.9991
(D)*(E)	2	176,755,000	0.76	0.4670
(B)*(D)*(E)	2	174,401,000	0.75	0.4717
(B)*(C)*(D)	2	26,670,000	0.12	0.8912
(B)*(C)*(E)	4	121,828,000	0.53	0.7166
(C)*(B)*(D)	4	54,820,000	0.24	0.9175
(B)*(C)*(D)*(E)	4	32,464,000	0.24	0.9672
Error	315	231,558,000		
Total	359			

* Significant at p<.05

** Significant at p<.001

Table 25 : Analysis of variance of raw data Glaremark - experiment 2.

Source	df	ANOVA MS	F-value	Pr>F
(A)Subject	9	16.04	9.27	0.0001**
(B)Replication	1	14.40	8.32	0.0042**
(C)Luminance	2	46.06	26.62	0.0001**
(D)Road scene	1	0.10	0.06	0.8103
(E)Car speed	2	1.91	1.10	0.3336
(B)*(C)	2	0.23	0.13	0.8782
(B)*(D)	1	0.54	0.31	0.5754
(B)*(E)	2	0.68	0.39	0.6776
(C)*(D)	2	0.21	0.12	0.8867
(C)*(E)	4	0.93	0.53	0.7144
(D)*(E)	2	1.25	0.72	0.4844
(B)*(D)*(E)	2	0.37	0.21	0.8080
(B)*(C)*(D)	2	0.69	0.40	0.6733
(B)*(C)*(E)	4	0.98	0.56	0.6898
(C)*(B)*(D)	4	1.03	0.59	0.6723
(B)*(C)*(D)*(E)	4	1.03	0.59	0.6642
Error	315	1.73		
Total	359			

* Significant at p<.05

** Significant at p<.001

Table 26 : Glaremark means by luminaire type (N=360).

Luminaire type	Means, Glaremark	Grouping	Relative value, %
90^{0} max CP	4.39	A	140
Realistic	4.03	B	130
Constant	3.18	C	100

Table 27 : Glaremark means by replication (N=360).

Replication	Means, Glaremark	Grouping	Relative value, %
1	4.07	A	111
2	3.67	B	100

The plot of the average Glaremark in each trial against the trial number (Figure 30) showed that the Glaremark value decreased as the trials increased. Another adjusted data analysis was done using the data, subtracting the average Glaremark score from the individual Glaremark score in each trial. The adjusted data was reanalyzed (Table 28). The results showed that there were no differences between the conclusions when using the raw data and adjusted data.

Main Effects - Relative Rating The Analysis of Variance procedure (Table 29) showed that luminaires were statistically significant (Table 30).

Correlation of BCD, Glaremark and Relative Rating The correlations among BCD, the Glaremark and relative rating on each condition were significant (Table 31).

Discussion

Luminaire Type Effect The luminaire type effect was found significant using BCD (Table 21), Glaremark rating (Table 26) and relative rating (Table 30). The order of comfort in the three methods was identical. The 90^{0} maximum candle power luminaire was most comfortable, the realistic luminaire was next and the constant luminance system was the least comfortable. Among the three criteria (Table 32), the relative rating was most sensitive, the BCD next, and the Glaremark least sensitive. The relative value of Table 32 indicates that the relative rating method spreads the means as well as reduces the error. It also permits calculation

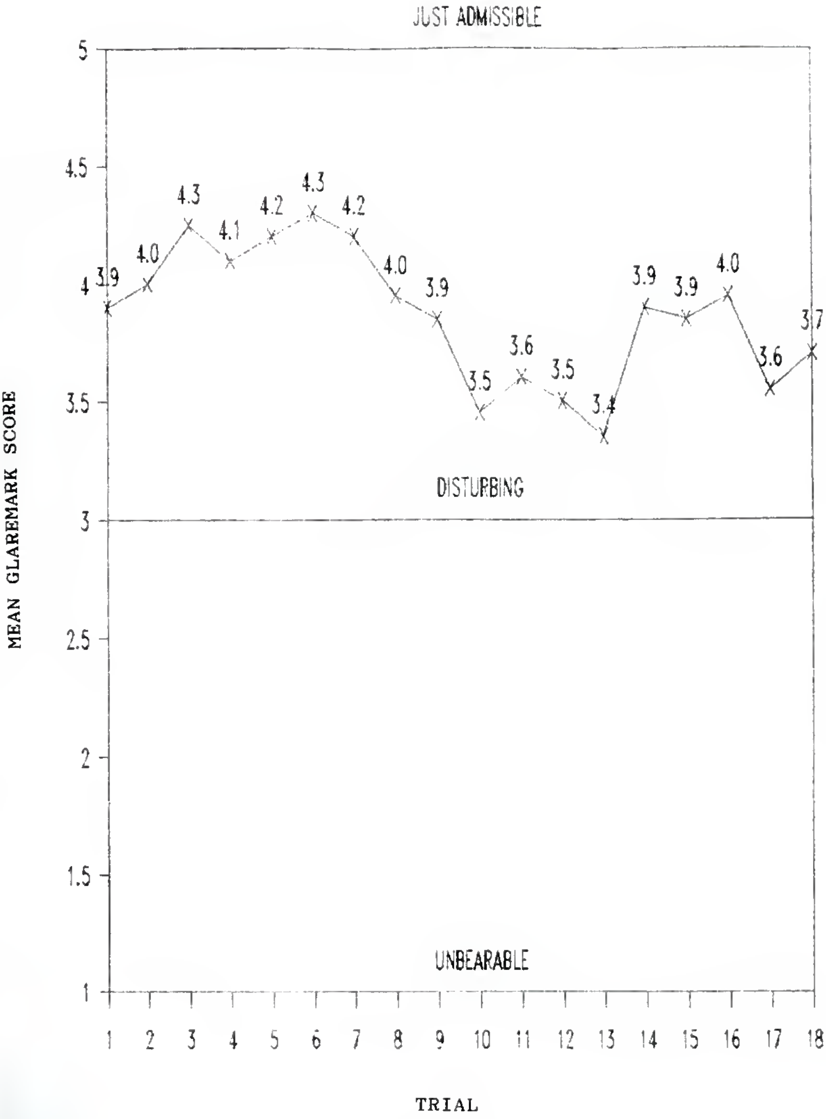

Figure 30 : Glaremark Mean vs. trial

Table 28 : Analysis of variance of Glaremark - experiment 2 (adjusted Glaremark).

Source	df	ANOVA MS	F-value	Pr>F
(A)Subject	9	16.04	9.04	0.0001**
(B)Replication	1	14.40	8.78	0.0033**
(C)Luminance	2	44.37	27.05	0.0001**
(D)Road scene	1	0.26	0.16	0.6900
(E)Car speed	2	1.38	0.84	0.4318
(B)*(C)	2	0.24	0.15	0.8634
(B)*(D)	1	0.42	0.26	0.6130
(B)*(E)	2	0.71	0.43	0.6498
(C)*(D)	2	0.32	0.19	0.8255
(C)*(E)	4	1.04	0.63	0.6397
(D)*(E)	2	2.11	1.29	0.2775
(B)*(D)*(E)	2	0.52	0.32	0.7284
(B)*(C)*(D)	2	0.72	0.44	0.6438
(B)*(C)*(E)	4	0.92	0.56	0.6934
(C)*(B)*(D)	4	1.41	0.86	0.4869
(B)*(C)*(D)*(E)	4	1.28	0.78	0.5378
Error	315	1.64		
Total	359			

* Significant at p<.05

** Significant at p<.001

Table 29 : Analysis of variance of relative rating - experiment 2.

Source	df	ANOVA MS	F-value	Prob.> F
Luminaires	2	0.3153	19.22	0.0001**
Error	33	0.0164		
Total	35			

** Significant at p<.001

Table 30 : Relative rating means by luminaire type (N=36).

Luminaire type	Means, weight	Grouping	Relative value, %
90^{0} max CP	.508	A	270
Realistic	.306	B	160
Constant	.186	C	100

Table 31 : Correlation of BCD Glaremark and relative rating.

<u>BCD vs Glaremark</u>

Pearson Correlation Coefficients (R)	0.43
Probability >|R| under RHO : R=0	0.00001 **
Number of Observations	360

<u>BCD vs relative rating</u>

Pearson Correlation Coefficients (R)	0.21
Probability >|R| under RHO : R=0	0.00001 **
Number of Observations	360

<u>Glaremark vs relative rating</u>

Pearson Correlation Coefficients (R)	0.31
Probability >|R| under RHO : R=0	0.00001 **
Number of Observations	360

** Significant at p<.001

Table 32 : Comparison among three criteria. A high number indicates the preferred luminaire.

Luminaire type	Relative value		
	BCD	Glaremark	relative rating
90^{0} max CP	170	140	270
Realistic	130	130	160
Constant	100	100	100

of a consistency ratio (not provided), which is very useful for detecting potential outliers. It has two disadvantages. First, it requires each possible pair to be presented for evaluation. Second, it requires conversions of the relative ratings into eigenvectors before the conventional statistical tests can be performed. Third, the subject in relative rating method can not be used as an factor ANOVA (it is subjected to the constraint that the sum of weights in eigenvectors for each subject must be equal to 1).

The coefficient of determination was 19% between BCD and Glaremark. This means that 81% is unexplained. Between Glaremark and relative rating, the coefficient of determination was 10%. The coefficient of determination was 6% between BCD and relative rating. The unexplained variabilities are large among BCD, Glaremark and Relative Rating.

BCD, Glaremark, relative rating and CBE The CBE indices (Table 4) are as follows :

(1) maximum CBE value (MAX),

(2) minimum CBE value (MIN),

(3) ratio of maximum and minimum CBE value (RA),

(4) difference of maximum and minimum CBE value (DI),

(5) average of maximum and minimum CBE value (AV),

(6) CBE per foot (PF).

The correlation of BCD, Glaremark (GM) and relative rating (WGT) vs CBE indices are shown in Table 33. The

Table 33 : The correlation of BCD, Glaremark and relative rating vs CBE indices.

	BCD	GM	WGT	MAX	MIN	PF	RA	DI	AV
BCD	==	.43	.19	-.22	.01	-.13	-.03	-.17	-.24
p-value		**	**	**	.72	*	.52	**	**
GM		==	.31	-.24	-.08	-.26	.06	-.14	-.33
p-value			**	**	.11	**	.25	**	**
WGT			==	-.66	.06	-.39	-.11	-.51	-.71
p-value				**	.27	**	*	**	**

* Significant at p<.05

** Significant at p<.001

average of maximum and minimum CBE value (AV) has the strongest negative relationship between BCD, Glaremark and relative rating. The relationship of minimum CBE value (MIN) and ratio of maximum and minimum CBE value (RA) between BCD, Glaremark and relative rating are not significant.

Three stepwise linear regression procedures were used to determine the CBE variables affecting the Glaremark rating, BCD and relative rating.

The independent variables are CBE indices (1) MAX, (2) MIN, (3) RA, (4) DI, (5) AV and (6) PF.

The result is shown in Table 34, Table 35 and Table 36.

For the Glaremark, the equation was :

Glaremark =

$$6.172 - 0.00497 \ (\ AV \ )$$

with $r^2 = 0.11$.

For the BCD, the equation was :

BCD =

$$54458 - 57 \ (\ AV \ )$$

with $r^2 = 0.06$.

For the relative rating, the equation was :

Weight =

$$0.963 - 0.00159 \ (\ AV \ ) + 0.00029 \ (\ PF \ )$$

with $r^2 = 0.53$.

In relative rating, the CBE per foot (PF) only accounts for 2% of the correlation of determination. This indicates that the main factor to determine the Glaremark, BCD and

Table 34 : Stepwise regression for Glaremark and CBE indices.

Dependent variable : Glaremark $r^2 = 0.11$

	df	Sum of square	Mean square	F	Pr >F
Regression	1	90.23	90.23	44.05	0.0001**
Error	358	733.37	2.05		
Total	359	823.60			

	Coefficient	Std error	F	Pr >F	Partial r^2
Intercept	6.172				
AV	-0.00497	0.000749	90.23	0.0001**	.11

** Significant at p<.001

Table 35 : Stepwise regression for BCD and CBE indices.

Dependent variable : BCD $r^2 = 0.06$

	df	Sum of square	Mean square	F	Pr >F
Regression	1	11,725,346,000	11,725,346,000	21.32	0.0001**
Error	358	192,997,068,000	549,849,000		
Total	359	204,722,415,000			

	Coefficient	Std error	F	Pr >F	Partial r^2
Intercept	54,458				
AV	-57	12.41	21.32	0.0001**	.06

** Significant at p<.001

Table 36 : Stepwise regression for relative rating and CBE indices.

Dependent variable : Weight $r^2 = 0.53$

	df	Sum of square	Mean square	F	Pr >F
Regression	1	6.70	6.70	368.44	0.0001**
Error	358	6.51	0.02		
Total	359	13.20			

	Coefficient	Std error	F	Pr >F	Partial r^2
Intercept	0.963				
AV	-0.00159	0.000096	277.82	0.0001**	.51
PF	0.00029	0.000079	13.37	0.0001**	.02

** Significant at p<.001

relative rating is average of maximum and minimum CBE value (AV). The negative coefficient indicates that if average of maximum and minimum CBE value (AV) increases, (i.e., light gets brighter) the Glaremark, BCD and relative weight decrease. The average of maximum and minimum CBE value can be explained that the overall glare impact to the subject during the driving. The higher average value, the more discomfort.

The r^2 of Glaremark and BCD vs CBE of only 11% and 6% separately suggests that Glaremark and BCD are relatively poor predictors of CBE. With a r^2 of 53%, relative rating is a good predictor of CBE.

Car Speed Effect The speed effect was not significant for either BCD (Table 20) or Glaremark (Table 25). The result was not compatible to the results of Easwer (1983) and Ganesh (1986). In their results, they found that a higher luminance level is required to produce the same degree of discomfort at a slower speed of 30 mph as compared to 60 mph, i.e., at the same installation, a speed of 30 mph was more comfortable than a speed of 60 mph.

The different can be explained two ways. First, in this experiment, car speeds of 40, 50 and 60 mph were used. The car speeds used in Easwer and Ganesh thesis were 30 mph and 60 mph. This may indicate that the car speed of 30 mph is a critical speed for comfort. If the car speed exceeds 30 mph, the degree of discomfort is not significant as the

speed goes higher. Second, in this experiment, a road scene was provided and the subject instruction focus point was "look at the intersection of the roadway at the horizon on the scene". The instruction sheet in Easwer and Ganesh didn't mention the subject focus point. In their experiment, the subjects may have looked at the occulder portion (light sources). The overall BCD in the Ganesh thesis was only 6,600 cd/m^2 and in the Easwer was 2,840 cd/m^2 compared to 28,000 cd/m^2 in this experiment. This indicates that if the driver focus is at the intersection of the roadway at the horizon, the sensation of discomfort is independent of the speed of the light moving toward the car (car speed).

The plot of CBE by time at different car speeds for the 90^0 maximum candle power luminaire is shown in Figure 31. The average CBE for the three different speeds was identical and equal to 370 CBE. Based on the discussion in the luminaire type effect and the result of car speed effect, this suggests that car speed didn't affect the sensation of discomfort. The reason is that the mean CBE per second is identical at different car speeds.

<u>Scene Effect</u> The scene effect was found not significant using both BCD (Table 20) and Glaremark (Table 25).

This can be explained that the different roadway luminance between two scenes was too small (1 cd/m^2 vs 2 cd/m^2). The study by de Boer et al.(1967) shows that the

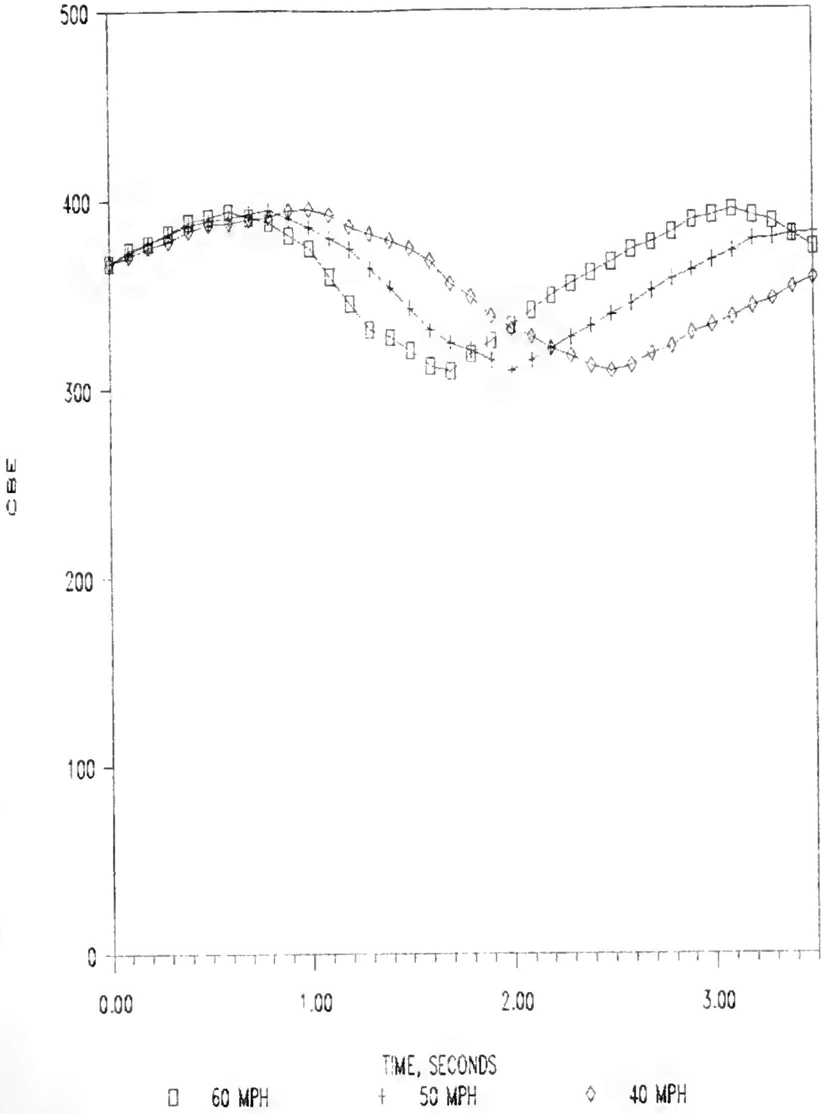

Figure 31: CBE by time at different car speeds

category of "good road lighting" occurs at an average road surface luminance of 1.5 cd/m^2.

EXPERIMENT 3

Task

With the same equipment as experiment 1, the screen was divided by a divider. The subject viewed the light source with the left eye and the pupil camera focused on the right eye. See Figure 14. The purpose of the divider was to avoid the interference of brightness of the spot to the pupillometer system. The subject adjusted the brightness of the source and pressed a key to the computer when he passed through BCD several times until reached his BCD point. The subject started with a low brightness spot (2,600 cd/m^2), increased brightness until he went past BCD, then lowered brightness and again passed through BCD, then increased the brightness (in several cycles) and stopped at BCD. A Gulf & Western, Applied Science Laboratory 1992S Eye View Monitor and TV pupillometer system was used to collect pupil diameter during the experiment.

Subjects

The criteria to determine a qualified subject for experiment 3 were : (1) capability to recognize BCD consistently and (2) have a big and round pupil shape. Subject 28 and 38 were used in this experiment. Each subject was paid $10.

Procedure and Experimental Design

When the subject reported to the laboratory, the subject read a description of the experiment (Figure 32) and

Informed consent statement
Simulator experiment - experiment 3

1. I,______________________________________, volunteer to participate in a project in connection with research studies to be conducted by Kansas State University.

2. I fully understand that the purpose of the study as outlined on the orientation statement attached to this sheet.

3. I also understand that my performance as an individual will be treated as research data and will in no way be associated with me for any other than identification purposes, thereby assuring anonymity of my performance and responses.

4. I understand that I am a volunteer for this research and that I may decline to participate with no penalty. I further understand that I will be permitted to leave the test at any time and I may discontinue participation without penalty, or loss of benefits to which I am otherwise entitled.

5. I understand that I can receive a payment of ten dollars. If I do not complete the session, I will receive only half the pay.

6. There is no compensation available from Kansas State University for injured subjects.

7. Pictures may be taken during the experiment. By agreeing to participate, I consent to your right to take pictures. Pictures may be published in professional reports or journals or shown at professional meetings.

8. A questionnaire will be used.

9. I understand that my age must be over 18 and less that 28. My vision must be approximately 20-20 without correction and I cannot wear contact lens or eyeglasses during the experiment.

10. If I have any questions regarding my rights as a test subject, injuries or emergencies resulting from my participation or any questions concerning the study, I understand that I can contact Tungshang Liu at 776-6501.

11. If I have any questions about my rights as a subject or the manner in which this research was conducted I will contact Dr. Robert Lowman, Chair, Committee on Research Involving Human Subjects, the Graduate School, KSU, Manhattan, Kansas 66506 or call (913) 532-6195.

I have read the Subject Orientation Statement, attached to this form, and signed the herein Informed Consent Statement this______ day of_________, 1989.

____
Signature

Figure 32 : Informed consent statement - experiment 3

indicated willingness to participate. The subject then was given a detailed instruction sheet (Figure 33) for the specific task.

The BCD adjustment procedure was the same as in experiment 1. With the pupillometer system, the fluctuation of the subject's pupil was measured during the BCD adjustment procedure. The subject was given 5 trials. There was a five minutes interval between each trial. There were three identified points of PSI in the changing amplitude of pupil size wave. For a single viewing, a PSI was determined by using 3 cycles centered on each keyed point. The PSIs for each trial were calculated.

The approximate time for the subject to complete the experiment was 30 minutes.

Measurements and Instrumentation

The subject's right pupil diameter was measured for the time during the BCD adjustment procedure in each trial. The time at which the subject passed the BCD point also was recorded. There were 15 readings per second i.e., 900 readings per minute.

Results

Useful pupil diameter data was only obtained on subject 38 in trial 3, 4 and 5 (BCD were 16,800 cd/m^2, 14,600 cd/m^2 and 11,600 cd/m^2 separately). The pupil fluctuation chart is shown in Appendix 5. The PSIs cna not be calculated because (1) the fluctuation of pupil diameters did not show

Experiment 3 instruction sheet

Pupil fluctuation - subject orientation statement

(Please read carefully)

Your age must be over 18 and less than 28. Your vision must be approximately 20 -20 without correction and you must not wear contact lenses or eye glasses during the experiment.

In this experiment we are going to measure the change of pupil diameter of your right eye through the eye scanning camera during BCD adjustment procedure. Please put your chin on the chinrest and your forehead on the headrest. Focus your eyes on the hole all the time. Avoid blinking your eye during the time the light of the spot is on.

Before the criteria trial, there will be two practice trials. After that, you will be repeating the same procedure for 5 times.

The experiment will take place in the Visual Simulation room, Durland 126. The approximate time for you to complete the session will be about 30 minutes. This will be 10 dollars for you to complte the session. If you have any question, please ask me. I will be glad to answer them.

Figure 33 : Experiment 3 instruction sheet

as expected in Figure 12 (a decreasing sinewave when luminance level increased and an increasing sinewave when the luminance level decreased) and (2) the points for calculating the PSIs were too close to each other (less than 3 cycles) in most BCD points.

Discussion

The attempt to find a correlation between PSI and the observer's subjective determination of BCD was unsuccessful. The change of pupil diameters depends on (1) the rate of increment or decrement of the light, (2) the BCD point adjusted, (3) the light pulse, and (4) the blinking of eyes. There are too many factors involving the fluctuation of the pupil. The problem of the pupillometer is that it can not filter out the variability when the subject blinks his eyes. So we can not distinguish the pupil change in the time of blinking eyes from the change in pupil diameter due to other factors. The effect of pupil diameter change during blinking eyes also is important. If the fluctuation of the pupil in BCD is smaller than in blinking eyes, then the pupil change in BCD is not easy to detect. The existing pupilmonitor system doesn't have the capability to eliminate the effect of blinking eyes and the scanning method of pupil diameter is not very steady.

CONCLUSION

In Experiment 1, the BCD value was significantly affected by initial luminance. The higher the initial luminance, the higher the BCD. The time to reach BCD was significant less in trials 6 - 11 than in trials 2 - 5. A method of determining qualified subjects was developed. Ten subjects out of 52 subjects with the capability to recognize BCD consistently and with a "non-extreme" BCD were chosen for experiment 2.

In Experiment 2, all three criteria (Glaremark, BCD and relative rating) were significantly different for all three luminaires. The 90^{0} maximum candle power luminaire was most comfortable, the realistic luminaire was next and the constant luminaire was the least comfortable. This result disagrees with the results of Ganesh. Note that this experiment used a selected group of subjects to minimize experimental variability. The numerical values may not be applicable if the the entire range of the driving population was used. Among the three criteria, the relative rating was most sensitive, the BCD next, and the Glaremark least sensitive. Also, the relative rating is a good predictor of CBE. The effect of scene and speed were not significant using either BCD or Glaremark.

In Experiment 3, there is no evidence to conclude that pupil diameter changes can be an index of BCD.

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APPENDICES

Appendix 1 : Demographic Variables Analysis

DEMOGRAPHIC VARIABLES ANALYSIS

Results

A correlational study was done using Experiment 1 data. The raw data is shown in Table 1. Mean BCD for all subjects was 12,700 cd/m^2. The range of ages was 18 to 28 with a mean of 22; 63 % were male; 43 % classified their eye color as brown (as opposed to 57 % green/blue). The percentages reporting various original hair color were : black - 18%, dark brown - 41%, light brown - 25%, blond - 14%, and red - 2%. The median hometown population size was 10,000 to 100,000.

Three different types of correlation coefficients were calculated (due to the nature of the several parameters and consistency with previous studies). For age, the usual product-moment correlation was calculated. For gender and eye color, one of the parameters is continuous and one of them is a genuine dichotomy, so biserial coefficients were used. For residential classification and hair color, a serial correlation was computed, as these are really continuous parameters which are artificially categorized into several categories.

As shown in Table 2, 3 of the 5 correlations(age, gender and eye color) are statistically significant. All of the correlation coefficients are small, indicating that only a small portion of the variance of BCD can be accounted for by these demographic variables.

Table 1 : Demographic data.

Subject	Mean BCD, cd/m^2	Age, Years	Sex	Size of Residence*	Eye Color	Hair Color⁺
1	13,200	26	Male	5	Br	1
2	12,800	21	Male	1	B/G	2
3	17,200	21	Male	1	B/G	2
4	8,900	23	Male	4	Br	3
5	4,400	21	Male	3	B/G	2
6	10,900	21	Male	3	B/G	2
7	12,100	23	Male	6	Br	1
8	4,900	21	Female	3	B/G	2
9	14,200	22	Male	4	B/G	3
10	21,300	21	Male	5	B/G	3
11	10,800	21	Male	4	Br	3
12	26,900	22	Female	5	B/G	4
13	13,100	22	Male	1	B/G	3
14	8,100	20	Female	4	Br	1
15	13,400	26	Female	6	Br	1
16	4,900	24	Male	6	Br	3
17	25,800	20	Female	5	B/G	4
18	14,400	19	Male	5	Br	2
19	16,800	21	Male	7	Br	1
20	15,100	24	Male	4	Br	1
21	17,500	19	Female	7	B/G	2
22	4,700	20	Female	5	Br	3
23	12,700	21	Male	7	Br	2
24	11,400	21	Male	6	Br	2
25	12,500	24	Male	5	Br	2
26	20,100	21	Male	5	B/G	2
27	21,000	28	Male	5	Br	1
28	6,500	19	Male	6	B/G	2
29	10,600	20	Female	4	B/G	2
30	17,100	22	Male	5	B/G	4
31	15,200	20	Female	4	Br	2
33	7,600	25	Female	5	Br	1
34	21,400	10	Male	3	B/G	3
35	23,200	19	Male	6	Br	2

Table 1 : Demographic data (Continued).

Subject	Mean BCD, cd/m²	Age, Years	Sex	Size of Residence*	Eye Color	Hair Color+
36	3,900	22	Female	5	B/G	4
37	6,300	20	Male	6	B/G	3
38	13,000	27	Female	5	B/G	3
39	10,900	21	Female	6	B/G	2
40	12,200	21	Male	4	Br	2
41	6,400	20	Female	3	B/G	2
42	7,300	23	Male	7	Br	2
43	16,100	21	Male	4	B/G	2
44	4,300	22	Male	3	B/G	3
45	18,600	21	Female	3	B/G	5
46	11,000	23	Female	5	B/G	4
47	5,000	26	Male	4	Br	1
48	17,400	20	Male	6	B/G	3
49	10,000	20	Female	5	B/G	2
50	5,500	19	Male	6	B/G	4
51	5,500	20	Female	5	B/G	4
52	16,400	28	Female	6	Br	3

*
1 = < 10
2 = 10 - 100
3 = 100 - 1,000
4 = 1,000 - 10,000
5 = 10,000 - 100,000
6 = 100,000 - 1,000,000
7 = > 1,000,000

\+
1 = Black
2 = Dark Brown
3 = Light Brown
4 = Blond
5 = Red

Table 2 : Correlations of demographic variables vs BCD.

Parameter	Age	Gender	Residential Population	Eye-Color	Hair-Color
Type of Coefficient	Product Moment	Point Biserial	Serial	Point Biserial	Serial
Present Study					
Correlation	-.09	.12	.06	-.09	.03
Significance	.05	.01	N.S.	.05	N.S.
Early Study II*					
Correlation	-.37+	.09	-.24	.85	.08
Significance	.01	N.S.	.05	.01	N.S.
Early Study I**					
Correlation	-.36	.08	.29	---	---
Significance	.01	N.S.	.01	---	---

*Bennett, C. A., "Discomfort Glare : demographic variables II", 1974.

*Bennett, C. A., "Discomfort Glare : demographic variables", 1972.

Discussion

Correlation Between BCD and Age

There was a significant, but small, negative correlation between BCD and age. This relationship, as in the earlier studies, was as age increased BCD decreased. The difference between the present study and the earlier studies is that the range of age for the present study was from 18 to 28. Even in the shorter age range, the result still confirmed the previous results. So age has some sort of effect.

Correlation Between BCD and Gender

The result found in this study was contradictory to previous studies. The correlation coefficient was significant in this study. It shows that females tend to have higher BCDs than males. Females had a mean BCD of 13,500 cd/m^2 while the males had a mean BCD of 12,300 cd/m^2.

Correlation Between BCD and Residential Population

The correlation coefficient was not significant in this study. A negative correlation was significant in the 1972 study and a positive correlation was significant in the 1974 study. Due to the small correlation and inconsistent relations in previous studies, we may conclude that the correlation between BCD and residential population size is probably insignificant.

Correlation Between BCD and Eye Color

A small, negative correlation was found between eye color "lightness" and BCD. In this study those with brown eyes(i.e. dark eyes) had a mean BCD of 12,000 cd/m^2 while those with blue or green eyes had a mean BCD of 13,200 cd/m^2. The previous studies showed that individuals with darker eye color would be less sensitive to glare. It seems that the correlation occurs by chance.

Correlation Between BCD and Hair Color

The result in this study was consistent with earlier study. The correlation between hair color and BCD was insignificant.

Appendix 2 :

BCD Comparison Between Experiment 1 and Experiment 2

BCD COMPARISON BETWEEN EXPERIMENT 1 AND EXPERIMENT 2

The mean and standard deviation of BCD for subjects participating in Experiment 1 and Experiment 2 is shown in Table 3. The mean BCD in the Experiment 1 and Experiment 2 is the subject's sensitivity to glare. Experiment 2 had a higher overall BCD than Experiment 1. The result can be explained by : (1) Viewing angle to light source : In Experiment 1, the glare source was in the line of sight. In Experiment 2, the angle between the light source and the line of sight varied from 0° to 20°. (2) Viewing distance to light source : The viewing distance was 100 cm in Experiment 1 and 107 cm in Experiment 2. (3) Glare source size : The source size was 7. cm^2 in Experiment 1 and varied from 0.1 cm^2 to 2.5 cm^2 in Experiment 2. In Bennett's (1977) study, the BCD is direct proportion to the exponential of the source angle above of the line of sight and is inversely proportional to the source size to the 0.6th power. The result t(hat Experiment 2 had a higher BCD) was compatible with Bennett's study.

The standard deviation in Experiment 1 is the consistency of the subject to the glare under the same condition and in Experiment 2 is the subject's sensitivity of the judgement of glare under different conditions. The correlation of the BCD mean and standard deviation in Experiment 1 and Experiment 2 is shown in Table 4. Only the correlation in Experiment 2 between mean BCD and standard

Table 3 : BCD (mean and standard deviation) in experiment 1 and experiment 2.

Subject No.		Exp.1		Exp.2	
Ex1	Ex2	BCD Mean, cd/m^2	Standard dev., cd/m^2	BCD Mean, cd/m^2	Standard dev., cd/m^2
1	38	13,000	2,210	28,900	13,820
2	25	12,500	2,300	16,700	8,870
3	49	10,000	1,030	8,700	5,920
4	7	12,100	1,210	19,200	13,210
5	28	6,500	500	19,600	10,020
6	31	15,200	480	46,900	32,670
7	46	11,000	1,540	27,400	14,640
8	18	14,400	870	19,600	9,570
9	11	10,800	1,370	20,600	10,020
10	23	12,700	2,370	72,500	25,940
Mean		11,820		28,010	

Table 4 : Correlation of BCD mean and standard deviation in Experiment 1 and Experiment 2.

	Mean BCD (Exp.1)	Standard Deviation (Exp.1)	Mean BCD (Exp.2)	Standard Deviation (Exp.2)
Mean BCD (Exp.1)	1	0.21	0.39	0.53
Standard deviation (Exp.1)	-	1	0.31	-0.02
Mean BCD (Exp.2)	-	-	1	0.86*
Standard deviation (Exp.2)	-	-	-	1

* Significant at $p < 0.001$

deviation is significant. A high mean BCD was related to a high standard deviation. The coefficient of determination of mean BCD vs standard deviation in Experiment 2 was $(0.86)^2 = 0.74$.

The mean BCD in Experiment 1 vs Experiment 2 (Figure 1) was plotted. Although not significant, a higher mean BCD in Experiment 1 tended to give a higher mean BCD in Experiment 2.

Figure 2 shows, for Experiment 2, mean BCD vs standard deviation. A higher mean BCD yielded a higher standard deviation. If a subject's sensitivity to glare is high, the variability of the estimate is high.

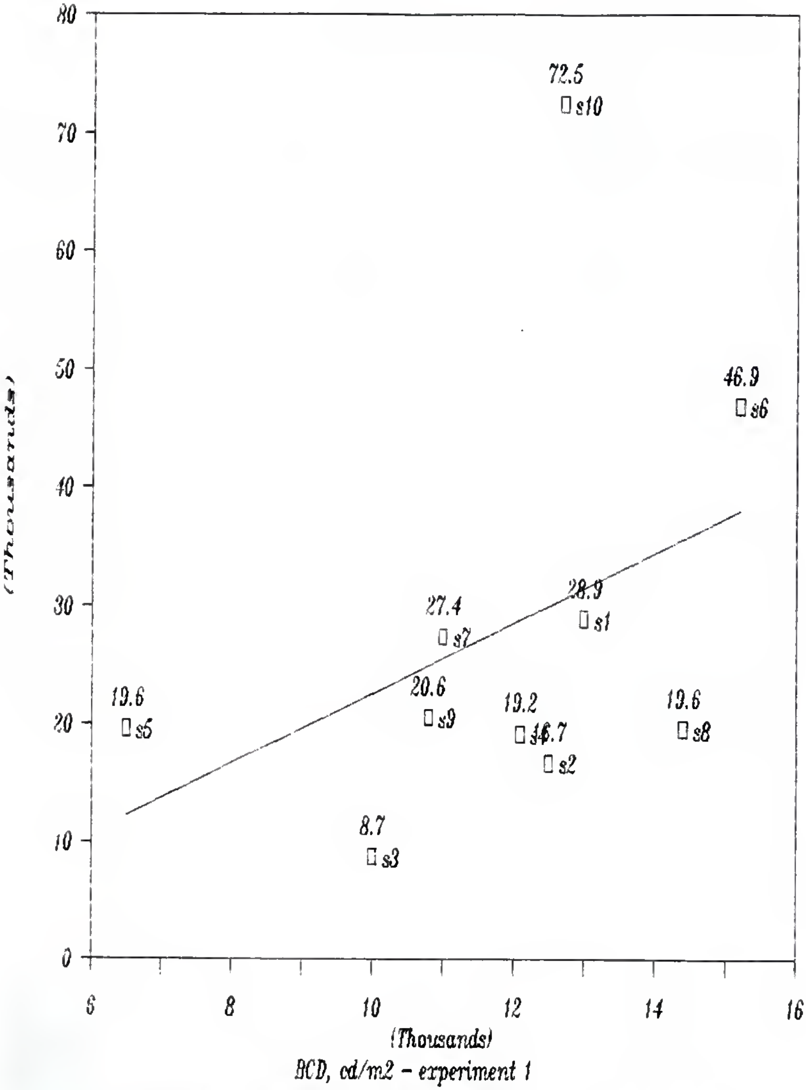

Figure 1 : Mean BCD Experiment 1 vs Experiment 2.

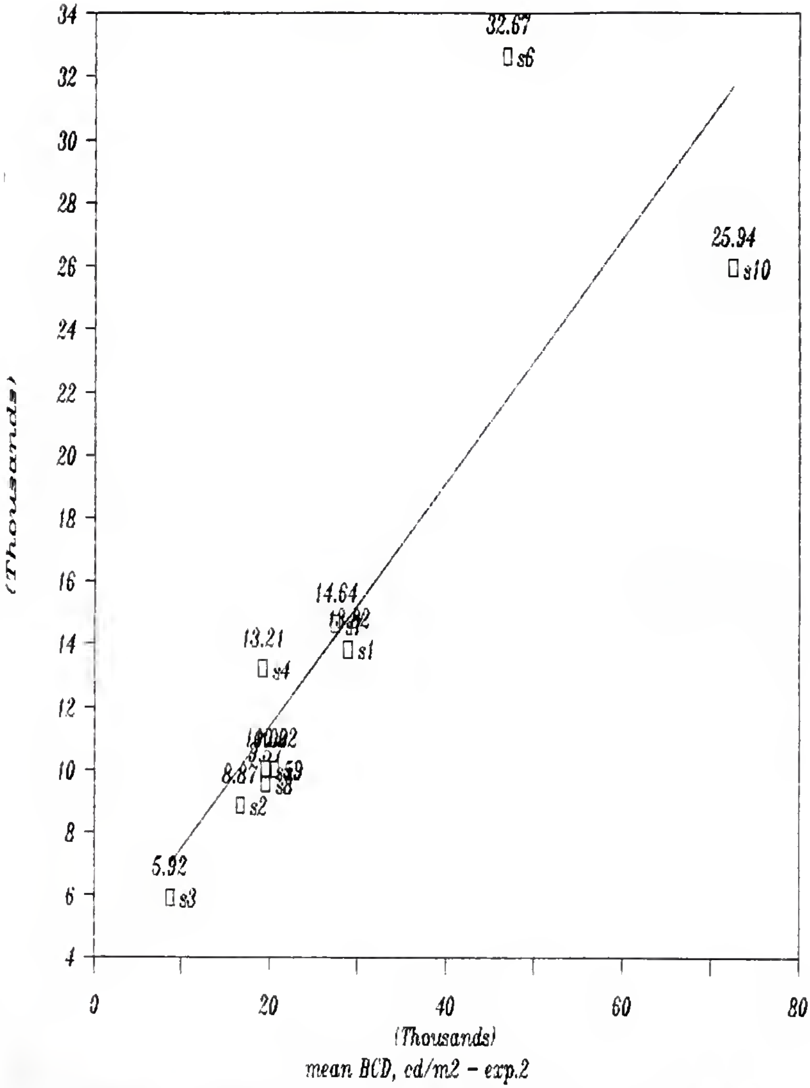

Figure 2 : Mean BCD vs Standard Deviation in Experiment 2.

Appendix 3 :

Overview of the Discomfort Glare Project

OVERVIEW OF THE DISCOMFORT GLARE PROJECT

February, 1988

1. Project started.

2. Chose Tungshang Liu as research assistant.

3. Sent the brightness spot meter and calibrated source to Photo Research for calibrating.

4. Organized modification of eye monitor system and the dynamic simulator.

March, 1988

1. Calibrate eye monitor.

2. Modified the simulator.

3. Ordered the computer I/O board to accept the voltage from the pupil monitor and feed into a IBM PC.

4. Started working on computer program and device for the time circuit.

5. Started working on the computer program for the pupil diameter gathering.

7. Started working on the relay control device.

8. Got eye view monitor set up and working.

April, 1988

1. Installed the computer I/O board to computer and tested OK.

2. Finished draft pupil diameter gathering program - 6 data per second.

3. Did the first test subject on the eye view monitor. The result was unacceptable.

4. Continued working on the time circuit program and device.

5. Continued working on the relay control device.

6. Continued working on the modification of the simulator.

May, 1988

1. Received the brightness spot meter and calibrated source from Photo Research.

2. Read brightness of the lamp in the simulator with spot meter. Also measured dimensions of holes.

3. Test pupil monitor on a person.

4. Took breadboard of relay control device to technician to change into a working model.

5. Completed the seat modification in simulator.

6. Determined reflectances of the color for the road scene.

June, 1988

1. Painted first draft of scene poster for replacement inside of simulator.

2. Completed time circuit program and device. Installed and test Ok.

3. Completed the relay control device. Installed and worked fine.

4. Got pupil monitor and BCD meter to work simultaneously on computer.

5. Got data from test subject. The light was on for

one second, off for three seconds. The pupil diameter dropped approximately 1 mm during the ON time and then rose gradually back the 1 mm over 3 seconds of OFF time.

6. Got data from test subject. Used three different light levels, Additional brightness decreases average pupil diameter. However at constant brightness there is no suggestion of any waveform that is regular.

7. Put two pieces of 1/8 inch thick opal glass for simulator.

8. Discussed project with Merle Keck about simulator, BCD meter and pupil monitor.

July, 1988

1. Changed the reading speed of data-gathering from 6 readings per second to 10 readings per second.

2. Determined brightness of milkglass with different lights in BCD meter. The brightness ranged from 60 cd/m^2 to 74,000 cd/m^2.

3. Got data from test subjects. The light was on for one second and off for one second three times, then off for five seconds.

4. Got data from test subjects. The light was on for one second and off for one second three times, then off for ten seconds.

August, 1988

1. Worked on data smoothing.

2. The pupil diameter did not return to its original diameter after the light was off 5 seconds. There seems to be a cumulative effect of the individual pulses; that is, diameter does not return to its prior state before the next pulse.

3. Started a pilot study in BCD meter and pupil monitor.

4. Changed the reading speed of data-gathering from 10 readings per second to maximum of 60 reading per second.

September, 1988

1. Converted the data-gathering program to IBM AT computer.

2. Analyzed data-gathering at 10,15,30 and 60 readings per second. Concluded that no additional benefit was obtained beyond 15 readings per second. Decided to use 15 readings/second in future studies.

3. Noticed that the eye diameter is not steady before the light comes on. Concluded that we need to have the subject control the location of where they are looking more precisely.

4. Ran data set for 6 conditions(3,300, 8,000 and 13,000 cd/m^2 with one second and .5 second pulses). Results were not good.

5. Reran data set for 6 conditions and calculated results for 6 conditions. Concluded :

1. One-second pulse of light is better than a half second pulse.

2. There may be a problem with the variability of the data in that there is a question of what to use for the baseline diameter and "bottom of the valley" values. change

6. Analyzed result of 6 conditions. Concluded :

1. A higher value of DPF (Dynamic Pupil Fluctuation) in low luminance of spot.

2. Some variability and inconsistency of the data.

October, 1988

1. Analyzed data for a time period of over one second. Noticed there seems to be considerable variability for three cycles of the same spot brightness and among the subjects. There did not seem to be a definite difference between the spot brightness.

2. Concluded that the eye begins to change diameter about .4 of a second after the light was turned on. The pupil diameter continued to dip for effectively all of the time that the light is on (for the entire one second). It did not seem to flatten, especially.

3. Returned to a 5 second gap between trials.

4. Tried 12 subjects on the pupil camera but pupil diameter worked only on three. This implied that we

may have problems getting good pupil diameter data on a random selection of subjects.

November, 1988

1. Concluded that subjects that are females tend to get diameters easier than males because of the upward curve of female eyelashes, making less interference with the camera.

2. Concluded that due to the basic random variability of the pupil diameter that it may be better to use the average of a number of cycles rather than using individual cycles.

3. Met with Merle Keck concerning project. Decided to try the cycles for longer time periods rather than just the one second on and off that we have being using previously.

4. Did trials at 3,300, 8,200 and 13,000 cd/m^2 at the 10 seconds on and 10 seconds off for 3 cycles.

Concluded that :

   1. We are dealing with "noisy" signal. There seems to be a great deal of variability from trial to trial, even for the same subject in the same condition.

   2. The camera was not able to pick up the eyeball when using 72,000 cd/m^2 of the spot.

December, 1988

1. Did trials at 3,300, 8,200 and 13,000 cd/m^2 at the 10 seconds on and 10 seconds off for 3 cycles.

Concluded that :

1. The second and third cycles of a trial seem to have an initial pupil diameter which does not come back to 6 mm. That is 10 seconds gap is not sufficient to completely recover.
2. The data after the light onset is very variable with no consistent pattern -- even keeping background and spot luminance constant. There also is no obvious effect of either background luminance or spot luminance.
3. Attempted to get a better "signal" by using a divider between the eyes to the target. The concept is that the brain will have both pupil diameters affected by the spot but the pupil diameter of the right eye will not be influenced by the light itself and thus will not distort any camera response.

4. A test was made of Border Between Comfort and Discomfort (BCD) for 12 subjects. The background was either 0 or 32 cd/m^2. The pulse train was 3, 1 second on and 1 second off, with 5 seconds off gap and adjusted once from maximum and once from minimum.

Concluded that :

1. The mean BCD for 32 cd/m^2 background was 8,370 for 0 cd/m^2 was 7,120. The difference was statistically significant.

2. The effect of sequence was significant.

3. There is great individual variability.

4. Needed more that 4 practice trials.

January, 1989 - February, 1989

1. Replaced the wedge-shaped glass with tempered glass on the simulator.

2. The filters arrived from Merle Keck. Mounted filters in the holders.

3. Modified simulator to make the overall height of the eye of the subject adjustable to horizon level.

4. Designed experiment testing BCD measurement. Carried out experiment and analyzed details. Concluded that : Position of the variac did not influence the BCD setting. The amount of practice did affect BCD setting.

5. Developed a ranking method to select the subjects based on minimum variability and nearness to average.

6. Planned a series of study with Experiment 1 being the screening study on BCD. Experiment 2 was the simulator study, not using pupil diameter. Experiment 3 used the pupil diameter.

March, 1989

1. Modified simulator to conform the requests of Keck and Fry.

1. Moved disk on simulator out so it does not rub.

2. Made changing the filter more convenient.

3. Minimized the dark adaption loss from the subject.

4. Move the inside variac to be operated from viewer position.

2. Dr. Fry recommended an alternative possibility - using a constant brightness source but putting a compensating filter in front of the light (in replace of the present procedure of adjusting the brightness of BCD spot with a variac).

3. Decided the retain the existing method of control of the brightness.

4. Decided the pulse train length - 2 second on with 2 seconds gap between pulses.

5. Began running subjects on the screening study (Experiment 1). Completed 30 of 52 subjects in Experiment 1.

April, 1989

1. Completed Experiment 1 (screening) : 52 subjects. Reduced the data. Selected 10 subjects for Experiment 2.

2. Completed Experiment 2 (simulator). Reduced data.

3. Draft Results from Experiment 1 and 2.

4. Completed experiment 3 (pupil diameter) on 2 subjects.

May,June, 1989

1. Reduced data for Experiment 3.

2. Completed draft of final thesis.

3. Completed the final thesis.

July, 1989

1. Liu off project.

2. Konz out of country for remainder of summer.

November, 1989

1. Short final report (draft) submitted.

Appendix 4 : Raw data - Experiment 1

Explanations :

SEQ : Trial Number

TYPE : Experience type

P : Practice
C : Criterion

LH : Initial Luminance

L : Low Initial Luminance
H : High Initial Luminance

TIME : BCD Adjusting Time, Seconds

BCD : Luminance Level at BCD, cd/m^2

SUBJECT=1

OBS	SEQ	TYPE	LH	TIME	BCD
1	1	P	L	37	3019
2	2	P	H	60	7392
3	3	P	L	25	6995
4	4	P	H	17	12416
5	5	P	L	21	10182
6	6	C	L	52	11422
7	7	C	H	28	17270
8	8	C	L	31	11174
9	9	C	H	18	15369
10	10	C	L	16	11894
11	11	C	H	32	11836

SUBJECT=2

OBS	SEQ	TYPE	LH	TIME	BCD
12	1	P	H	115	6561
13	2	P	L	30	7308
14	3	P	H	29	11621
15	4	P	L	26	12764
16	5	P	H	34	16578
17	6	C	H	33	13634
18	7	C	L	29	11174
19	8	C	H	33	12706
20	9	C	L	40	10827
21	10	C	H	41	14562
22	11	C	L	50	13924

SUBJECT=3

OBS	SEQ	TYPE	LH	TIME	BCD
23	1	P	L	79	12242
24	2	P	H	73	23620
25	3	P	L	56	21716
26	4	P	H	50	22508
27	5	P	L	53	13150
28	6	C	H	57	19400
29	7	C	L	58	18950
30	8	C	H	26	19400
31	9	C	L	29	12474
32	10	C	H	32	17212
33	11	C	L	27	16002

SUBJECT=4

OBS	SEQ	TYPE	LH	TIME	BCD
34	1	P	H	40	12590
35	2	P	L	32	8148
36	3	P	H	25	16002
37	4	P	L	21	11670
38	5	P	H	24	10311
39	6	C	H	21	11075
40	7	C	L	20	11778
41	8	C	H	21	12706
42	9	C	L	25	8190
43	10	C	H	21	6235
44	11	C	L	21	3624

SUBJECT=5

OBS	SEQ	TYPE	LH	TIME	BCD
45	1	P	L	112	3461
46	2	P	H	54	6380
47	3	P	L	46	4257
48	4	P	H	53	5712
49	5	P	L	33	4663
50	6	C	L	56	3624
51	7	C	H	35	5135
52	8	C	L	37	4141
53	9	C	H	40	4083
54	10	C	L	33	4460
55	11	C	H	41	4634

SUBJECT=6

OBS	SEQ	TYPE	LH	TIME	BCD
56	1	P	H	77	5837
57	2	P	L	64	12300
58	3	P	H	81	13950
59	4	P	L	41	19000
60	5	P	H	48	13500
61	6	C	H	43	15542
62	7	C	L	40	12126
63	8	C	H	53	7812
64	9	C	L	40	3248
65	10	C	H	44	10154
66	11	C	L	56	11798

SUBJECT=7

OBS	SEQ	TYPE	LH	TIME	BCD
67	1	P	L	114	15450
68	2	P	H	60	19604
69	3	P	L	46	18284
70	4	P	H	28	15050
71	5	P	L	45	11024
72	6	C	H	29	11855
73	7	C	L	28	13410
74	8	C	H	35	13871
75	9	C	L	32	11198
76	10	C	H	20	10908
77	11	C	L	32	11613

SUBJECT=8

OBS	SEQ	TYPE	LH	TIME	BCD
78	1	P	L	38	6958
79	2	P	H	44	7306
80	3	P	L	37	3561
81	4	P	H	59	4497
82	5	P	L	44	2812
83	6	C	L	36	5628
84	7	C	H	25	4715
85	8	C	L	28	5113
86	9	C	H	36	4715
87	10	C	L	60	5221
88	11	C	H	19	3918

SUBJECT=9

OBS	SEQ	TYPE	LH	TIME	BCD
89	1	P	L	90	7256
90	2	P	H	80	10328
91	3	P	L	54	11720
92	4	P	H	45	15350
93	5	P	L	37	12258
94	6	C	L	56	12413
95	7	C	H	61	13468
96	8	C	L	59	14562
97	9	C	H	45	15050
98	10	C	L	47	13526
99	11	C	H	49	16050

SUBJECT=10

OBS	SEQ	TYPE	LH	TIME	BCD
100	1	P	L	113	29131
101	2	P	H	12	22930
102	3	P	L	10	25320
103	4	P	H	9	16200
104	5	P	L	9	25680
105	6	C	L	9	21540
106	7	C	H	10	23250
107	8	C	L	9	22690
108	9	C	H	10	18680
109	10	C	L	9	22690
110	11	C	H	9	18546

SUBJECT=11

OBS	SEQ	TYPE	LH	TIME	BCD
111	1	P	L	54	13065
112	2	P	H	38	12028
113	3	P	L	34	16150
114	4	P	H	39	11720
115	5	P	L	37	11720
116	6	C	L	33	12892
117	7	C	H	28	10734
118	8	C	L	37	10792
119	9	C	H	20	3694
120	10	C	L	34	11314
121	11	C	H	33	10270

SUBJECT=12

OBS	SEQ	TYPE	LH	TIME	BCD
122	1	P	L	76	31613
123	2	P	H	39	34700
124	3	P	L	48	22100
125	4	P	H	40	34700
126	5	P	L	34	16300
127	6	C	L	37	13548
128	7	C	H	52	33952
129	8	C	L	42	21914
130	9	C	H	54	32642
131	10	C	L	45	22772
132	11	C	H	54	31300

SUBJECT=13

OBS	SEQ	TYPE	LH	TIME	BCD
133	1	P	L	91	4779
134	2	P	H	54	6706
135	3	P	L	29	7686
136	4	P	H	39	3736
137	5	P	L	25	8442
138	6	C	L	22	6995
139	7	C	H	25	10430
140	8	C	L	17	13286
141	9	C	H	23	16233
142	10	C	L	21	15369
143	11	C	H	25	16118

SUBJECT=14

OBS	SEQ	TYPE	LH	TIME	BCD
144	1	P	H	89	4033
145	2	P	L	88	12358
146	3	P	H	55	14735
147	4	P	L	93	9438
148	5	P	H	95	10926
149	6	C	H	75	10430
150	7	C	L	62	10331
151	8	C	H	77	6995
152	9	C	L	90	4637
153	10	C	H	90	6452
154	11	C	L	62	9339

SUBJECT=15

OBS	SEQ	TYPE	LH	TIME	BCD
155	1	P	H	35	8998
156	2	P	L	23	16866
157	3	P	H	30	9994
158	4	P	L	26	13576
159	5	P	H	25	12126
160	6	C	H	37	14214
161	7	C	L	55	13692
162	8	C	H	26	13460
163	9	C	L	14	16406
164	10	C	H	29	13402
165	11	C	L	18	9389

-- SUBJECT=16 ----------------

OBS	SEQ	TYPE	LH	TIME	BCD
166	1	P	L	92	3677
167	2	P	H	42	4286
168	3	P	L	82	4170
169	4	P	H	69	4286
170	5	P	L	46	4750
171	6	C	L	42	5547
172	7	C	H	46	3834
173	8	C	L	34	5096
174	9	C	H	50	4439
175	10	C	L	47	5402
176	11	C	H	18	4953

-- SUBJECT=17 ----------------

OBS	SEQ	TYPE	LH	TIME	BCD
177	1	P	L	173	9290
178	2	P	H	45	15542
179	3	P	L	50	30630
180	4	P	H	37	24580
181	5	P	L	48	26020
182	6	C	L	56	27220
183	7	C	H	29	27140
184	8	C	L	38	25540
185	9	C	H	25	25100
186	10	C	L	29	24260
187	11	C	H	25	24660

-- SUBJECT=18 ----------------

OBS	SEQ	TYPE	LH	TIME	BCD
188	1	P	L	61	17500
189	2	P	H	62	26660
190	3	P	L	49	15830
191	4	P	H	43	26290
192	5	P	L	46	11422
193	6	C	H	45	14620
194	7	C	L	48	15254
195	8	C	H	51	15311
196	9	C	L	58	13054
197	10	C	H	41	14330
198	11	C	L	33	13808

SUBJECT=19

OBS	SEQ	TYPE	LH	TIME	BCD
199	1	P	L	27	16406
200	2	P	H	34	13228
201	3	P	L	22	14446
202	4	P	H	13	10530
203	5	P	L	10	13286
204	6	C	L	19	13344
205	7	C	H	17	12764
206	8	C	L	20	17800
207	9	C	H	16	16406
208	10	C	L	14	21122
209	11	C	H	8	19200

SUBJECT=20

OBS	SEQ	TYPE	LH	TIME	BCD
210	1	P	H	72	34700
211	2	P	L	62	11836
212	3	P	H	61	8064
213	4	P	L	110	6416
214	5	P	H	78	8148
215	6	C	H	117	11836
216	7	C	L	139	11224
217	8	C	H	138	21336
218	9	C	L	98	13518
219	10	C	H	74	18550
220	11	C	L	95	14330

SUBJECT=21

OBS	SEQ	TYPE	LH	TIME	BCD
221	1	P	L	54	19600
222	2	P	H	21	19850
223	3	P	L	23	20792
224	4	P	H	22	22838
225	5	P	L	26	19800
226	6	C	L	33	21584
227	7	C	H	22	14096
228	8	C	L	18	17950
229	9	C	H	16	17270
230	10	C	L	13	13700
231	11	C	H	18	15542

SUBJECT=22

OBS	SEQ	TYPE	LH	TIME	BCD
232	1	P	H	158	5511
233	2	P	L	56	3915
234	3	P	H	49	4806
235	4	P	L	26	4141
236	5	P	H	62	3938
237	6	C	H	53	5127
238	7	C	L	33	5547
239	8	C	H	54	6537
240	9	C	L	26	3416
241	10	C	H	28	3706
242	11	C	L	21	3619

SUBJECT=23

OBS	SEQ	TYPE	LH	TIME	BCD
243	1	P	L	35	7980
244	2	P	H	22	18250
245	3	P	L	41	11522
246	4	P	H	20	15484
247	5	P	L	24	12648
248	6	C	L	21	13634
249	7	C	H	22	16060
250	8	C	L	25	10430
251	9	C	H	22	12830
252	10	C	L	26	9587
253	11	C	H	25	13692

SUBJECT=24

OBS	SEQ	TYPE	LH	TIME	BCD
254	1	P	L	20	11720
255	2	P	H	30	11720
256	3	P	L	17	16982
257	4	P	H	16	17800
258	5	P	L	16	15023
259	6	C	L	18	12590
260	7	C	H	13	10629
261	8	C	L	10	15542
262	9	C	H	13	8778
263	10	C	L	13	11836
264	11	C	H	13	9030

-- SUBJECT=25 ------------------

OBS	SEQ	TYPE	LH	TIME	BCD
265	1	P	H	134	11836
266	2	P	L	79	13460
267	3	P	H	51	17950
268	4	P	L	62	13460
269	5	P	H	70	12532
270	6	C	H	70	9636
271	7	C	L	67	14966
272	8	C	H	95	12416
273	9	C	L	61	13112
274	10	C	H	61	14735
275	11	C	L	77	9835

-- SUBJECT=26 ------------------

OBS	SEQ	TYPE	LH	TIME	BCD
276	1	P	H	239	13634
277	2	P	L	79	17600
278	3	P	H	63	17800
279	4	P	L	55	17850
280	5	P	H	59	20132
281	6	C	H	67	19400
282	7	C	L	81	15945
283	8	C	H	58	19850
284	9	C	L	51	20396
285	10	C	H	34	21122
286	11	C	L	43	24020

-- SUBJECT=27 ------------------

OBS	SEQ	TYPE	LH	TIME	BCD
287	1	P	L	441	19550
288	2	P	H	62	19100
289	3	P	L	46	17700
290	4	P	H	53	20726
291	5	P	L	53	19450
292	6	C	L	73	20462
293	7	C	H	62	21584
294	8	C	L	57	17039
295	9	C	H	65	20330
296	10	C	L	57	23234
297	11	C	H	65	24180

SUBJECT=28

OBS	SEQ	TYPE	LH	TIME	BCD
298	1	P	H	65	4605
299	2	P	L	30	5909
300	3	P	H	15	3736
301	4	P	L	23	6271
302	5	P	H	21	6235
303	6	C	H	30	7031
304	7	C	L	18	6742
305	8	C	H	17	5932
306	9	C	L	18	5601
307	10	C	H	22	6778
308	11	C	L	22	6742

SUBJECT=29

OBS	SEQ	TYPE	LH	TIME	BCD
309	1	P	H	99	21452
310	2	P	L	69	18200
311	3	P	H	81	13750
312	4	P	L	76	13054
313	5	P	H	93	14793
314	6	C	H	93	15196
315	7	C	L	80	11323
316	8	C	H	85	9736
317	9	C	L	97	9984
318	10	C	H	88	9198
319	11	C	L	97	8106

SUBJECT=30

OBS	SEQ	TYPE	LH	TIME	BCD
320	1	P	H	48	14908
321	2	P	L	35	14850
322	3	P	H	34	15426
323	4	P	L	42	18400
324	5	P	H	39	18050
325	6	C	H	34	16578
326	7	C	L	33	17700
327	8	C	H	30	15803
328	9	C	L	29	18050
329	10	C	H	26	16578
330	11	C	L	29	17800

SUBJECT=31

OBS	SEQ	TYPE	LH	TIME	BCD
331	1	P	H	45	33110
332	2	P	L	25	24740
333	3	P	H	21	17335
334	4	P	L	14	20792
335	5	P	H	14	15630
336	6	C	H	14	14966
337	7	C	L	17	14793
338	8	C	H	12	15837
339	9	C	L	17	14620
340	10	C	H	13	15369
341	11	C	L	17	15484

SUBJECT=33

OBS	SEQ	TYPE	LH	TIME	BCD
342	1	P	H	51	6380
343	2	P	L	30	4460
344	3	P	H	42	6669
345	4	P	L	47	6344
346	5	P	H	49	7182
347	6	C	H	30	9198
348	7	C	L	29	7896
349	8	C	H	30	7812
350	9	C	L	26	7622
351	10	C	H	29	6054
352	11	C	L	26	7224

SUBJECT=34

OBS	SEQ	TYPE	LH	TIME	BCD
353	1	P	H	59	15023
354	2	P	L	43	12532
355	3	P	H	41	17385
356	4	P	L	50	16463
357	5	P	H	57	28740
358	6	C	H	30	29280
359	7	C	L	66	23234
360	8	C	H	36	21650
361	9	C	L	56	18500
362	10	C	H	53	18700
363	11	C	L	61	16982

-- SUBJECT=35 --

OBS	SEQ	TYPE	LH	TIME	BCD
364	1	P	H	126	9637
365	2	P	L	38	12126
366	3	P	H	42	15369
367	4	P	L	33	23470
368	5	P	H	30	21782
369	6	C	H	33	19400
370	7	C	L	46	20528
371	8	C	H	37	25860
372	9	C	L	25	26500
373	10	C	H	25	20462
374	11	C	L	33	26500

-- SUBJECT=36 --

OBS	SEQ	TYPE	LH	TIME	BCD
375	1	P	H	38	10034
376	2	P	L	33	5945
377	3	P	H	22	4953
378	4	P	L	19	5243
379	5	P	H	27	4402
380	6	C	H	21	5272
381	7	C	L	26	4431
382	8	C	H	22	3387
383	9	C	L	21	3329
384	10	C	H	22	3764
385	11	C	L	21	3416

-- SUBJECT=37 --

OBS	SEQ	TYPE	LH	TIME	BCD
386	1	P	L	102	4257
387	2	P	H	74	5402
388	3	P	L	82	3532
389	4	P	H	46	5243
390	5	P	L	42	4112
391	6	C	L	41	4431
392	7	C	H	66	7896
393	8	C	L	45	7031
394	9	C	H	57	5801
395	10	C	L	42	5728
396	11	C	H	81	7140

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SUBJECT=38

OBS	SEQ	TYPE	LH	TIME	BCD
397	1	P	H	55	19800
398	2	P	L	90	24100
399	3	P	H	51	9885
400	4	P	L	57	10827
401	5	P	H	41	13866
402	6	C	H	27	16290
403	7	C	L	49	13170
404	8	C	H	45	12890
405	9	C	L	74	14338
406	10	C	H	36	10083
407	11	C	L	30	11224

SUBJECT=39

OBS	SEQ	TYPE	LH	TIME	BCD
408	1	P	L	121	10282
409	2	P	H	200	10926
410	3	P	L	109	13634
411	4	P	H	98	9835
412	5	P	L	94	12358
413	6	C	L	92	10877
414	7	C	H	78	12996
415	8	C	L	63	12300
416	9	C	H	70	11224
417	10	C	L	49	8736
418	11	C	H	62	9587

SUBJECT=40

OBS	SEQ	TYPE	LH	TIME	BCD
419	1	P	H	109	16521
420	2	P	L	75	8022
421	3	P	H	138	6054
422	4	P	L	406	4779
423	5	P	H	226	5301
424	6	C	H	149	6561
425	7	C	L	135	14793
426	8	C	H	129	15196
427	9	C	L	186	12300
428	10	C	H	105	13576
429	11	C	L	106	10530

SUBJECT=41

OBS	SEQ	TYPE	LH	TIME	BCD
430	1	P	L	86	5837
431	2	P	H	134	5366
432	3	P	L	109	5656
433	4	P	H	92	5127
434	5	P	L	94	6633
435	6	C	L	82	6163
436	7	C	H	63	7182
437	8	C	L	83	5439
438	9	C	H	78	6959
439	10	C	L	66	5909
440	11	C	H	94	6706

SUBJECT=42

OBS	SEQ	TYPE	LH	TIME	BCD
441	1	P	L	65	2662
442	2	P	H	87	7350
443	3	P	L	73	5185
444	4	P	H	58	6778
445	5	P	L	62	6416
446	6	C	L	50	6959
447	7	C	H	54	8106
448	8	C	L	38	6995
449	9	C	H	57	7560
450	10	C	L	38	7812
451	11	C	H	46	6488

SUBJECT=43

OBS	SEQ	TYPE	LH	TIME	BCD
452	1	P	H	170	30990
453	2	P	L	32	8106
454	3	P	H	30	20396
455	4	P	L	30	15434
456	5	P	H	17	16924
457	6	C	H	21	14930
458	7	C	L	19	19600
459	8	C	H	18	15420
460	9	C	L	22	17270
461	10	C	H	17	14562
462	11	C	L	21	14908

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SUBJECT=44

OBS	SEQ	TYPE	LH	TIME	BCD
463	1	P	H	37	14040
464	2	P	L	29	10778
465	3	P	H	28	7306
466	4	P	L	20	6018
467	5	P	H	21	6778
468	6	C	H	20	7140
469	7	C	L	21	4547
470	8	C	H	25	3882
471	9	C	L	25	3184
472	10	C	H	17	3648
473	11	C	L	20	3126

SUBJECT=45

OBS	SEQ	TYPE	LH	TIME	BCD
474	1	P	L	74	11224
475	2	P	H	38	16060
476	3	P	L	30	18150
477	4	P	H	30	15254
478	5	P	L	17	15369
479	6	C	L	17	17600
480	7	C	H	21	20198
481	8	C	L	17	19100
482	9	C	H	25	18750
483	10	C	L	14	18400
484	11	C	H	14	17327

SUBJECT=46

OBS	SEQ	TYPE	LH	TIME	BCD
485	1	P	H	115	13808
486	2	P	L	34	13402
487	3	P	H	30	16694
488	4	P	L	22	16406
489	5	P	H	20	7812
490	6	C	H	16	10877
491	7	C	L	15	13402
492	8	C	H	23	10083
493	9	C	L	19	12184
494	10	C	H	14	9389
495	11	C	L	21	9885

SUBJECT=47

OBS	SEQ	TYPE	LH	TIME	BCD
496	1	P	L	114	5620
497	2	P	H	69	5873
498	3	P	L	37	6090
499	4	P	H	65	4953
500	5	P	L	57	6344
501	6	C	L	25	5214
502	7	C	H	41	5156
503	8	C	L	53	4257
504	9	C	H	41	4721
505	10	C	L	42	5301
506	11	C	H	34	4750

SUBJECT=48

OBS	SEQ	TYPE	LH	TIME	BCD
507	1	P	H	80	36063
508	2	P	L	70	26100
509	3	P	H	62	17800
510	4	P	L	66	13100
511	5	P	H	70	16694
512	6	C	H	75	14562
513	7	C	L	58	16233
514	8	C	H	54	17800
515	9	C	L	66	17550
516	10	C	H	65	19250
517	11	C	L	67	18850

SUBJECT=49

OBS	SEQ	TYPE	LH	TIME	BCD
518	1	P	L	62	9030
519	2	P	H	61	12358
520	3	P	L	70	11472
521	4	P	H	69	10678
522	5	P	L	52	9156
523	6	C	L	57	11224
524	7	C	H	41	11174
525	8	C	L	49	9686
526	9	C	H	45	10232
527	10	C	L	54	8820
528	11	C	H	45	9072

-- SUBJECT=50 ------------------

OBS	SEQ	TYPE	LH	TIME	BCD
529	1	P	H	63	6525
530	2	P	L	52	10133
531	3	P	H	120	9610
532	4	P	L	22	10132
533	5	P	H	18	5011
534	6	C	H	22	5656
535	7	C	L	30	5040
536	8	C	H	18	5127
537	9	C	L	26	5127
538	10	C	H	18	6380
539	11	C	L	26	5511

-- SUBJECT=51 ------------------

OBS	SEQ	TYPE	LH	TIME	BCD
540	1	P	L	29	19400
541	2	P	H	17	16463
542	3	P	L	25	6054
543	4	P	H	73	10877
544	5	P	L	25	8400
545	6	C	L	29	5656
546	7	C	H	29	2662
547	8	C	L	25	4518
548	9	C	H	41	6307
549	10	C	L	29	5366
550	11	C	H	46	3694

-- SUBJECT=52 ------------------

OBS	SEQ	TYPE	LH	TIME	BCD
551	1	P	H	107	5837
552	2	P	L	63	.
553	3	P	H	67	3568
554	4	P	L	32	6850
555	5	P	H	99	7104
556	6	C	H	87	17850
557	7	C	L	58	16694
558	8	C	H	62	16002
559	9	C	L	70	14735
560	10	C	H	65	16290
561	11	C	L	67	16924

Appendix 5 : Raw data (BCD) - Experiment 2

Explanations :

SEQ : Trial Number.

TYPE : Criterion type

A : BCD
B : Glaremark

FS : Order in the Experiment

F : First
S : Second

LUM : Luminaires Type

R : Realistic
9 : 90 ^{o} Maximum Candlepower
C : Constant

SCE : Scene Type

A : See Table 7
B : See Table 7

SPD : Car Speed

4 : 40 mph
5 : 50 mph
6 : 60 mph

BCDGM: Luminance Level at BCD, cd/m ^{2}

SAS

------------------------------------ SUBJECT=1 REP=1 ------------------------------------

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
1	A	F	1	C	A	6	13639
2	A	F	2	9	A	4	38921
3	A	F	3	9	B	5	45552
4	A	F	4	R	A	6	35820
5	A	F	5	C	A	4	22400
6	A	F	6	C	B	5	18345
7	A	F	7	9	A	6	34110
8	A	F	8	R	A	4	41495
9	A	F	9	R	B	5	52585
10	A	F	10	C	B	4	15923
11	A	F	11	9	A	5	33450
12	A	F	12	9	B	6	27840
13	A	F	13	R	B	4	15735
14	A	F	14	C	A	5	24490
15	A	F	15	C	B	6	37068
16	A	F	16	9	B	4	55736
17	A	F	17	R	A	5	21247
18	A	F	18	R	B	6	26774

------------------------------------ SUBJECT=1 REP=2 ------------------------------------

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
19	A	S	1	9	A	6	44552
20	A	S	2	R	A	4	50905
21	A	S	3	R	B	5	47991
22	A	S	4	C	A	6	39693
23	A	S	5	9	A	4	31389
24	A	S	6	9	B	5	37800
25	A	S	7	R	A	6	36867
26	A	S	8	C	A	4	17814
27	A	S	9	C	B	5	16700
28	A	S	10	R	B	6	26330
29	A	S	11	C	B	4	17198
30	A	S	12	9	A	5	30932
31	A	S	13	9	B	6	23950
32	A	S	14	R	B	4	11895
33	A	S	15	C	A	5	11698
34	A	S	16	C	B	6	8317
35	A	S	17	9	B	4	11410
36	A	S	18	R	A	5	6971

---------------------------------- SUBJECT=2 REP=1 ----------------------------------

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
37	A	F	1	R	A	4	11410
38	A	F	2	R	B	5	8816
39	A	F	3	C	A	6	5891
40	A	F	4	9	A	4	12928
41	A	F	5	9	B	5	19341
42	A	F	6	R	A	6	15829
43	A	F	7	R	B	6	11994
44	A	F	8	C	B	4	8527
45	A	F	9	9	A	5	13885
46	A	F	10	C	A	4	7843
47	A	F	11	C	B	5	9345
48	A	F	12	9	A	6	12775
49	A	F	13	9	B	6	11895
50	A	F	14	R	B	4	6355
51	A	F	15	C	A	5	10326
52	A	F	16	C	B	6	6913
53	A	F	17	9	B	4	14390
54	A	F	18	R	A	5	7777

---------------------------------- SUBJECT=2 REP=2 ----------------------------------

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
55	A	S	1	C	A	4	22525
56	A	S	2	C	B	5	21614
57	A	S	3	9	A	6	22269
58	A	S	4	R	A	4	45755
59	A	S	5	R	B	5	19003
60	A	S	6	C	A	6	12699
61	A	S	7	9	A	4	20632
62	A	S	8	9	B	5	16798
63	A	S	9	R	A	6	23033
64	A	S	10	R	B	4	44158
65	A	S	11	C	A	5	17097
66	A	S	12	C	B	6	14825
67	A	S	13	9	B	4	20391
68	A	S	14	R	A	5	27840
69	A	S	15	R	B	6	17299
70	A	S	16	C	B	4	18345
71	A	S	17	9	A	5	17097
72	A	S	18	9	B	6	22009

SAS

---------------------------------- SUBJECT=3 REP=1 ----------------------------------

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
73	A	S	1	9	A	5	23422
74	A	S	2	9	B	6	17198
75	A	S	3	R	B	4	7089
76	A	S	4	C	A	5	6855
77	A	S	5	C	B	6	9988
78	A	S	6	9	B	4	17503
79	A	S	7	R	A	5	11698
80	A	S	8	R	B	6	9345
81	A	S	9	C	B	4	5842
82	A	S	10	R	A	6	3167
83	A	S	11	C	A	4	12195
84	A	S	12	C	B	5	11037
85	A	S	13	9	A	6	9345
86	A	S	14	R	A	4	2140
87	A	S	15	R	B	5	3300
88	A	S	16	C	A	6	3134
89	A	S	17	9	A	4	15092
90	A	S	18	9	B	5	7976

---------------------------------- SUBJECT=3 REP=2 ----------------------------------

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
91	A	F	1	9	B	5	25606
92	A	F	2	R	A	6	7909
93	A	F	3	C	A	4	7843
94	A	F	4	C	B	4	3567
95	A	F	5	9	A	5	15364
96	A	F	6	9	B	6	12699
97	A	F	7	R	B	4	5507
98	A	F	8	C	A	5	4507
99	A	F	9	C	B	6	5016
100	A	F	10	9	B	4	13478
101	A	F	11	R	A	5	2603
102	A	F	12	R	B	6	2976
103	A	F	13	R	A	4	3465
104	A	F	14	R	B	5	3782
105	A	F	15	C	A	6	3499
106	A	F	16	9	A	4	10240
107	A	F	17	C	B	5	2372
108	A	F	18	9	A	6	5215

------------------------------------ SUBJECT=4 REP=1 ------------------------------------

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
109	A	F	1	R	A	4	30481
110	A	F	2	R	B	5	17198
111	A	F	3	C	A	6	13161
112	A	F	4	9	A	4	17097
113	A	F	5	9	B	5	16404
114	A	F	6	R	A	6	6408
115	A	F	7	C	A	4	5599
116	A	F	8	C	B	5	7069
117	A	F	9	9	A	6	6196
118	A	F	10	9	B	6	13968
119	A	F	11	R	B	4	3356
120	A	F	12	C	A	5	3499
121	A	F	13	C	B	6	4463
122	A	F	14	9	B	4	13083
123	A	F	15	R	A	5	3673
124	A	F	16	R	B	6	3567
125	A	F	17	C	B	4	3431
126	A	F	18	9	A	5	8180

------------------------------------ SUBJECT=4 REP=2 ------------------------------------

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
127	A	S	1	C	A	4	43573
128	A	S	2	C	B	5	31543
129	A	S	3	9	A	6	56200
130	A	S	4	R	A	4	25042
131	A	S	5	R	B	5	20876
132	A	S	6	C	B	4	18131
133	A	S	7	9	A	5	36328
134	A	S	8	9	B	6	24990
135	A	S	9	R	B	4	29435
136	A	S	10	C	A	6	26184
137	A	S	11	9	A	4	32482
138	A	S	12	9	B	5	41312
139	A	S	13	R	A	6	18345
140	A	S	14	C	A	5	18781
141	A	S	15	C	A	6	17503
142	A	S	16	9	B	4	38821
143	A	S	17	R	A	5	14825
144	A	S	18	R	B	6	17503

SAS

SUBJECT=5 REP=1

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
145	A	S	1	C	B	4	14390
146	A	S	2	9	A	5	22009
147	A	S	3	9	B	6	31236
148	A	S	4	R	B	4	18239
149	A	S	5	C	A	5	15364
150	A	S	6	C	B	6	11395
151	A	S	7	9	B	4	19685
152	A	S	8	R	A	5	13398
153	A	S	9	R	B	6	21752
154	A	S	10	C	B	5	7583
155	A	S	11	9	A	6	15273
156	A	S	12	R	A	4	13239
157	A	S	13	R	B	5	3111
158	A	S	14	C	A	6	13885
159	A	S	15	9	A	4	8457
160	A	S	16	9	B	5	19115
161	A	S	17	R	A	6	15003
162	A	S	18	C	A	4	10765

SUBJECT=5 REP=2

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
163	A	F	1	9	A	5	47594
164	A	F	2	9	B	6	50655
165	A	F	3	R	B	4	31853
166	A	F	4	C	A	5	22778
167	A	F	5	C	B	6	17097
168	A	F	6	9	B	4	26477
169	A	F	7	R	A	5	23816
170	A	F	8	R	B	6	12474
171	A	F	9	C	A	6	13359
172	A	F	10	9	A	4	37800
173	A	F	11	9	B	5	23552
174	A	F	12	R	A	6	23291
175	A	F	13	C	A	4	19003
176	A	F	14	C	B	5	19455
177	A	F	15	9	A	6	21372
178	A	F	16	R	A	4	10499
179	A	F	17	R	B	5	11127
180	A	F	18	C	B	4	12623

SUBJECT=6 REP=1

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
181	A	S	1	9	A	6	75420
182	A	S	2	R	A	4	110187
183	A	S	3	R	B	5	96716
184	A	S	4	C	A	6	55045
185	A	S	5	9	A	4	121000
186	A	S	6	9	B	5	70147
187	A	S	7	R	A	6	66657
188	A	S	8	C	A	4	46369
189	A	S	9	C	B	5	51290
190	A	S	10	9	A	5	59719
191	A	S	11	9	B	6	72057
192	A	S	12	R	B	4	79241
193	A	S	13	C	A	5	55274
194	A	S	14	C	B	6	17097
195	A	S	15	9	B	4	42996
196	A	S	16	R	A	5	121000
197	A	S	17	R	B	6	100360
198	A	S	18	C	B	4	51718

SUBJECT=6 REP=2

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
199	A	F	1	R	B	4	34446
200	A	F	2	C	A	5	13968
201	A	F	3	C	B	6	28786
202	A	F	4	9	B	4	20035
203	A	F	5	R	A	5	26038
204	A	F	6	R	B	6	33614
205	A	F	7	C	B	4	22269
206	A	F	8	9	A	5	19801
207	A	F	9	9	B	6	30333
208	A	F	10	C	A	4	23422
209	A	F	11	C	B	5	16997
210	A	F	12	9	A	6	32166
211	A	F	13	R	A	4	19455
212	A	F	14	R	B	5	14305
213	A	F	15	C	A	6	3602
214	A	F	16	9	A	4	16700
215	A	F	17	9	B	5	31698
216	A	F	18	R	A	6	10155

SAS

------------------------------------ SUBJECT=7 REP=1 ------------------------

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
217	A	F	1	R	B	6	65105
218	A	F	2	C	B	4	33124
219	A	F	3	9	A	5	41435
220	A	F	4	9	B	6	36350
221	A	F	5	R	B	4	22962
222	A	F	6	C	A	5	24903
223	A	F	7	C	B	6	13639
224	A	F	8	9	B	4	33944
225	A	F	9	R	A	5	27531
226	A	F	10	C	B	5	31389
227	A	F	11	9	A	6	67447
228	A	F	12	R	A	4	14052
229	A	F	13	R	B	5	11895
230	A	F	14	C	A	6	10155
231	A	F	15	9	A	4	29273
232	A	F	16	9	B	5	31698
233	A	F	17	R	A	6	17503
234	A	F	18	C	A	4	10499

------------------------------------ SUBJECT=7 REP=2 ------------------------

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
235	A	S	1	C	A	6	20272
236	A	S	2	9	A	4	53024
237	A	S	3	9	B	5	47200
238	A	S	4	R	A	6	29109
239	A	S	5	R	B	6	31084
240	A	S	6	C	B	4	15003
241	A	S	7	9	A	5	45350
242	A	S	8	9	B	6	33450
243	A	S	9	R	B	4	22905
244	A	S	10	C	A	4	16018
245	A	S	11	C	B	5	15923
246	A	S	12	9	A	6	22778
247	A	S	13	R	A	4	17919
248	A	S	14	C	A	5	12400
249	A	S	15	C	B	6	9905
250	A	S	16	9	B	4	24490
251	A	S	17	R	A	5	20391
252	A	S	18	R	B	5	15092

------------------------------------ SUBJECT=8 REP=1 ------------------------------------

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
253	A	F	1	C	B	5	20391
254	A	F	2	9	A	6	27840
255	A	F	3	R	A	4	20876
256	A	F	4	R	B	5	15735
257	A	F	5	C	A	6	9423
258	A	F	6	9	A	4	20999
259	A	F	7	9	B	5	19003
260	A	F	8	R	A	6	9423
261	A	F	9	C	A	4	6248
262	A	F	10	C	A	5	8890
263	A	F	11	C	B	6	9423
264	A	F	12	9	B	4	17710
265	A	F	13	R	A	5	10765
266	A	F	14	R	B	6	7332
267	A	F	15	C	B	4	6355
268	A	F	16	9	A	5	13968
269	A	F	17	9	B	6	16789
270	A	F	18	R	B	4	5842

------------------------------------ SUBJECT=8 REP=2 ------------------------------------

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
271	A	S	1	9	B	6	43767
272	A	S	2	9	B	4	25464
273	A	S	3	C	A	5	17919
274	A	S	4	C	B	6	19570
275	A	S	5	9	B	4	21247
276	A	S	6	R	A	5	22400
277	A	S	7	R	B	6	15364
278	A	S	8	C	B	4	25606
279	A	S	9	9	A	5	34784
280	A	S	10	R	A	6	30185
281	A	S	11	C	A	4	26184
282	A	S	12	C	B	5	16897
283	A	S	13	9	A	6	35645
284	A	S	14	R	A	4	19801
285	A	S	15	R	B	5	19341
286	A	S	16	C	A	6	12775
287	A	S	17	9	A	4	31389
288	A	S	18	9	B	5	38821

SUBJECT=9 REP=1

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
289	A	S	1	R	A	6	44354
290	A	S	2	C	A	4	42427
291	A	S	3	C	B	5	33124
292	A	S	4	9	A	5	39517
293	A	S	5	9	B	6	38478
294	A	S	6	R	B	4	21372
295	A	S	7	C	A	5	21752
296	A	S	8	C	B	6	18313
297	A	S	9	9	B	4	22269
298	A	S	10	R	A	5	14914
299	A	S	11	R	B	6	17401
300	A	S	12	C	B	4	8317
301	A	S	13	9	A	6	20035
302	A	S	14	R	B	5	14825
303	A	S	15	C	A	6	8457
304	A	S	16	9	A	4	20035
305	A	S	17	9	B	5	22778
306	A	S	18	R	A	4	7777

SUBJECT=9 REP=2

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
307	A	F	1	R	B	5	32009
308	A	F	2	C	A	6	15456
309	A	F	3	9	A	4	34446
310	A	F	4	9	B	5	32302
311	A	F	5	R	A	6	19685
312	A	F	6	C	A	4	15003
313	A	F	7	C	B	5	16404
314	A	F	8	9	A	6	21498
315	A	F	9	R	A	4	13239
316	A	F	10	9	B	6	14650
317	A	F	11	R	B	4	14476
318	A	F	12	C	A	5	13558
319	A	F	13	C	B	6	14825
320	A	F	14	9	B	4	20272
321	A	F	15	R	A	5	15548
322	A	F	16	R	B	6	11602
323	A	F	17	C	B	4	7583
324	A	F	18	9	A	5	13398

SAS

SUBJECT=10 REP=1

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
325	A	S	1	C	A	4	44949
326	A	S	2	C	B	5	50655
327	A	S	3	9	A	6	54316
328	A	S	4	R	A	4	64343
329	A	S	5	R	B	5	45552
330	A	S	6	C	A	6	44949
331	A	S	7	9	A	4	108021
332	A	S	8	9	B	6	72331
333	A	S	9	R	B	4	40765
334	A	S	10	C	A	5	56434
335	A	S	11	9	B	5	121000
336	A	S	12	R	A	6	53913
337	A	S	13	C	B	6	48191
338	A	S	14	9	B	4	93589
339	A	S	15	R	A	5	47991
340	A	S	16	R	B	6	37068
341	A	S	17	C	B	4	56434
342	A	S	18	9	A	5	121000

SUBJECT=10 REP=2

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
343	A	F	1	9	A	5	70147
344	A	F	2	9	B	6	99130
345	A	F	3	R	A	6	51290
346	A	F	4	C	A	5	54137
347	A	F	5	C	B	6	68514
348	A	F	6	9	B	4	111445
349	A	F	7	R	A	5	87275
350	A	F	8	R	B	6	82939
351	A	F	9	C	B	4	60189
352	A	F	10	R	B	4	66136
353	A	F	11	9	A	6	120315
354	A	F	12	R	A	4	64091
355	A	F	13	R	B	5	68784
356	A	F	14	C	A	6	76285
357	A	F	15	9	A	4	111129
358	A	F	16	9	B	5	119975
359	A	F	17	C	A	4	70700
360	A	F	18	C	B	5	66657

Appendix 6 : Raw data (Glaremark) - Experiment 2

Explanations :

SEQ : Trial Number.

TYPE : Criterion type

A : BCD
B : Glaremark

FS : Order in the Experiment

F : First
S : Second

LUM : Luminaires Type

R : Realistic
9 : 90 ^{o} Maximum Candlepower
C : Constant

SCE : Scene Type

A : See Table 7
B : See Table 7

SPD : Car Speed

4 : 40 mph
5 : 50 mph
6 : 60 mph

BCDGM: Glaremark Rating, dimensionless

SUBJECT=1 REP=1

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
1	G	S	1	C	B	4	3
2	G	S	2	9	A	5	5
3	G	S	3	9	B	5	5
4	G	S	4	R	B	4	6
5	G	S	5	C	A	5	4
6	G	S	6	C	B	5	4
7	G	S	7	9	B	4	6
8	G	S	8	R	A	4	3
9	G	S	9	R	B	5	3
10	G	S	10	C	A	6	4
11	G	S	11	9	A	4	5
12	G	S	12	9	B	5	5
13	G	S	13	R	A	6	6
14	G	S	14	C	A	4	3
15	G	S	15	C	B	5	3
16	G	S	16	9	A	6	5
17	G	S	17	R	B	6	4
18	G	S	18	R	A	5	4

SUBJECT=1 REP=2

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
19	G	F	1	9	A	5	5
20	G	F	2	R	A	4	6
21	G	F	3	R	B	5	6
22	G	F	4	C	A	6	5
23	G	F	5	9	A	4	6
24	G	F	6	9	B	5	6
25	G	F	7	R	A	5	5
26	G	F	8	C	A	4	4
27	G	F	9	C	B	5	3
28	G	F	10	R	B	6	4
29	G	F	11	C	B	4	3
30	G	F	12	9	A	5	4
31	G	F	13	9	B	6	4
32	G	F	14	R	B	4	5
33	G	F	15	C	A	5	4
34	G	F	16	C	B	6	4
35	G	F	17	9	B	4	5
36	G	F	18	R	A	5	5

------------------------------------ SUBJECT=2 REP=1 ------------------------------------

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
37	G	S	1	R	B	6	3
38	G	S	2	C	B	4	3
39	G	S	3	9	A	5	4
40	G	S	4	9	B	6	3
41	G	S	5	R	B	4	4
42	G	S	6	C	A	5	2
43	G	S	7	C	B	6	3
44	G	S	8	9	B	4	3
45	G	S	9	R	A	5	4
46	G	S	10	R	B	5	4
47	G	S	11	C	A	6	2
48	G	S	12	9	A	4	3
49	G	S	13	9	B	5	4
50	G	S	14	R	A	6	5
51	G	S	15	C	A	4	3
52	G	S	16	C	B	5	3
53	G	S	17	9	A	6	4
54	G	S	18	R	A	4	4

------------------------------------ SUBJECT=2 REP=2 ------------------------------------

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
55	G	F	1	9	A	4	4
56	G	F	2	9	B	4	5
57	G	F	3	R	A	5	6
58	G	F	4	R	B	6	5
59	G	F	5	C	B	4	4
60	G	F	6	9	A	5	4
61	G	F	7	9	B	6	4
62	G	F	8	R	B	4	5
63	G	F	9	C	A	5	3
64	G	F	10	C	B	6	2
65	G	F	11	C	A	6	3
66	G	F	12	C	A	4	3
67	G	F	13	C	B	5	3
68	G	F	14	9	A	6	4
69	G	F	15	R	A	4	5
70	G	F	16	R	B	5	5
71	G	F	17	9	B	5	3
72	G	F	18	R	A	6	4

SUBJECT=3 REP=1

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
73	G	F	1	9	A	6	4
74	G	F	2	R	A	4	3
75	G	F	3	R	B	5	3
76	G	F	4	C	A	6	4
77	G	F	5	9	A	4	4
78	G	F	6	9	B	5	5
79	G	F	7	R	A	6	3
80	G	F	8	C	A	4	3
81	G	F	9	C	B	5	4
82	G	F	10	R	A	5	4
83	G	F	11	R	B	6	3
84	G	F	12	C	B	4	2
85	G	F	13	9	A	5	2
86	G	F	14	9	B	6	3
87	G	F	15	R	B	4	4
88	G	F	16	C	A	5	3
89	G	F	17	C	B	6	2
90	G	F	18	9	B	4	4

SUBJECT=3 REP=2

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
91	G	S	1	9	B	5	3
92	G	S	2	R	A	6	2
93	G	S	3	C	A	4	2
94	G	S	4	C	B	5	3
95	G	S	5	9	B	4	3
96	G	S	6	R	A	5	2
97	G	S	7	R	B	6	3
98	G	S	8	C	B	4	2
99	G	S	9	9	A	4	4
100	G	S	10	9	A	6	4
101	G	S	11	R	A	4	4
102	G	S	12	R	B	5	3
103	G	S	13	C	A	6	2
104	G	S	14	9	A	5	3
105	G	S	15	9	B	6	3
106	G	S	16	R	B	4	3
107	G	S	17	C	A	5	2
108	G	S	18	C	B	6	2

---------------------------------- SUBJECT=4 REP=1 ----------------------------------

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
109	G	S	1	R	A	5	1
110	G	S	2	R	B	6	1
111	G	S	3	C	B	4	3
112	G	S	4	9	A	5	3
113	G	S	5	9	B	6	3
114	G	S	6	R	B	4	3
115	G	S	7	C	A	5	1
116	G	S	8	C	B	6	2
117	G	S	9	9	B	4	5
118	G	S	10	9	B	5	5
119	G	S	11	R	A	6	2
120	G	S	12	C	A	4	3
121	G	S	13	C	B	5	3
122	G	S	14	9	A	6	5
123	G	S	15	R	A	4	4
124	G	S	16	R	B	5	3
125	G	S	17	C	A	6	2
126	G	S	18	9	A	4	4

---------------------------------- SUBJECT=4 REP=2 ----------------------------------

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
127	G	F	1	C	A	6	6
128	G	F	2	C	B	6	4
129	G	F	3	9	B	4	4
130	G	F	4	R	A	5	3
131	G	F	5	R	B	6	3
132	G	F	6	C	B	4	2
133	G	F	7	9	A	5	6
134	G	F	8	9	B	6	5
135	G	F	9	R	B	4	3
136	G	F	10	C	A	5	2
137	G	F	11	R	A	6	4
138	G	F	12	C	A	4	4
139	G	F	13	C	B	5	2
140	G	F	14	9	A	6	4
141	G	F	15	R	A	4	3
142	G	F	16	R	B	5	4
143	G	F	17	9	A	4	6
144	G	F	18	9	B	5	5

SAS

SUBJECT=5 REP=1

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
145	G	F	1	C	B	5	4
146	G	F	2	9	A	6	5
147	G	F	3	R	A	4	6
148	G	F	4	R	B	5	5
149	G	F	5	C	A	6	7
150	G	F	6	9	A	4	8
151	G	F	7	9	B	5	7
152	G	F	8	R	A	6	9
153	G	F	9	C	A	4	7
154	G	F	10	9	B	4	5
155	G	F	11	R	A	5	4
156	G	F	12	R	B	6	4
157	G	F	13	C	B	4	2
158	G	F	14	9	A	5	5
159	G	F	15	9	B	6	5
160	G	F	16	R	B	4	4
161	G	F	17	C	A	5	3
162	G	F	18	C	B	6	2

SUBJECT=5 REP=2

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
163	G	S	1	9	A	4	2
164	G	S	2	9	B	5	5
165	G	S	3	R	A	6	3
166	G	S	4	C	A	4	4
167	G	S	5	C	B	4	4
168	G	S	6	9	A	5	6
169	G	S	7	9	B	6	5
170	G	S	8	R	B	4	6
171	G	S	9	C	A	5	4
172	G	S	10	C	B	6	5
173	G	S	11	9	B	4	5
174	G	S	12	R	A	5	6
175	G	S	13	R	B	6	5
176	G	S	14	R	A	4	6
177	G	S	15	R	B	5	6
178	G	S	16	C	A	6	7
179	G	S	17	C	B	5	5
180	G	S	18	9	A	6	4

SUBJECT=6 REP=1

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
181	G	F	1	R	A	5	9
182	G	F	2	R	B	6	7
183	G	F	3	C	B	4	7
184	G	F	4	9	A	5	7
185	G	F	5	9	B	6	7
186	G	F	6	R	B	4	9
187	G	F	7	C	A	5	5
188	G	F	8	C	B	6	7
189	G	F	9	9	B	4	7
190	G	F	10	9	A	4	5
191	G	F	11	9	B	5	5
192	G	F	12	R	A	6	5
193	G	F	13	C	A	4	5
194	G	F	14	C	B	5	5
195	G	F	15	9	A	6	5
196	G	F	16	R	A	4	7
197	G	F	17	R	B	5	5
198	G	F	18	C	A	6	5

SUBJECT=6 REP=2

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
199	G	S	1	R	B	5	3
200	G	S	2	C	A	6	1
201	G	S	3	C	B	6	1
202	G	S	4	9	B	4	3
203	G	S	5	R	A	5	3
204	G	S	6	R	B	6	1
205	G	S	7	C	B	4	1
206	G	S	8	9	A	6	3
207	G	S	9	R	A	4	1
208	G	S	10	9	A	4	3
209	G	S	11	9	B	5	3
210	G	S	12	R	A	6	1
211	G	S	13	9	A	5	1
212	G	S	14	9	B	6	1
213	G	S	15	R	B	4	3
214	G	S	16	C	A	5	1
215	G	S	17	C	A	4	1
216	G	S	18	C	B	5	1

SUBJECT=7 REP=1

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
217	G	S	1	C	A	4	3
218	G	S	2	C	B	5	3
219	G	S	3	9	A	6	5
220	G	S	4	R	A	4	4
221	G	S	5	R	B	5	3
222	G	S	6	C	A	6	3
223	G	S	7	9	A	4	5
224	G	S	8	9	B	5	4
225	G	S	9	R	A	6	3
226	G	S	10	C	B	4	2
227	G	S	11	9	A	5	4
228	G	S	12	9	B	6	3
229	G	S	13	R	B	4	2
230	G	S	14	C	A	5	3
231	G	S	15	C	B	6	4
232	G	S	16	9	B	4	4
233	G	S	17	R	A	5	3
234	G	S	18	R	B	6	4

SUBJECT=7 REP=2

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
235	G	F	1	C	B	4	3
236	G	F	2	9	A	5	5
237	G	F	3	9	B	6	4
238	G	F	4	R	B	4	4
239	G	F	5	C	A	5	3
240	G	F	6	C	B	6	4
241	G	F	7	9	B	4	8
242	G	F	8	R	A	5	4
243	G	F	9	R	B	6	4
244	G	F	10	C	A	6	3
245	G	F	11	9	A	4	5
246	G	F	12	9	B	5	4
247	G	F	13	R	A	6	3
248	G	F	14	C	A	4	2
249	G	F	15	C	B	5	4
250	G	F	16	9	A	6	6
251	G	F	17	R	A	4	4
252	G	F	18	R	B	5	4

SUBJECT=8 REP=1

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
253	G	S	1	9	A	4	3
254	G	S	2	9	B	4	4
255	G	S	3	R	A	5	3
256	G	S	4	R	B	6	3
257	G	S	5	C	B	4	2
258	G	S	6	9	A	5	4
259	G	S	7	9	B	6	4
260	G	S	8	R	B	4	2
261	G	S	9	C	A	5	2
262	G	S	10	C	B	6	1
263	G	S	11	9	B	5	4
264	G	S	12	R	A	6	2
265	G	S	13	C	A	4	1
266	G	S	14	C	B	5	2
267	G	S	15	9	A	6	5
268	G	S	16	R	A	4	4
269	G	S	17	R	B	5	3
270	G	S	18	C	A	6	1

SUBJECT=8 REP=2

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
271	G	F	1	R	A	4	4
272	G	F	2	R	B	5	4
273	G	F	3	C	A	6	3
274	G	F	4	9	A	4	4
275	G	F	5	9	B	5	4
276	G	F	6	R	A	6	4
277	G	F	7	C	A	4	3
278	G	F	8	C	B	5	2
279	G	F	9	9	A	6	3
280	G	F	10	R	A	5	3
281	G	F	11	R	B	6	3
282	G	F	12	C	B	4	2
283	G	F	13	9	A	5	5
284	G	F	14	9	B	6	4
285	G	F	15	R	B	4	2
286	G	F	16	C	A	5	4
287	G	F	17	C	B	6	3
288	G	F	18	9	B	4	4

SUBJECT=9 REP=1

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
289	G	F	1	R	A	6	4
290	G	F	2	C	A	4	4
291	G	F	3	C	B	5	4
292	G	F	4	9	A	6	5
293	G	F	5	R	A	4	7
294	G	F	6	R	B	6	7
295	G	F	7	C	B	4	4
296	G	F	8	9	A	4	4
297	G	F	9	9	B	5	5
298	G	F	10	R	B	5	4
299	G	F	11	C	A	6	3
300	G	F	12	9	A	5	4
301	G	F	13	9	B	6	4
302	G	F	14	R	B	4	6
303	G	F	15	C	A	5	3
304	G	F	16	C	B	6	3
305	G	F	17	9	B	4	5
306	G	F	18	R	A	5	4

SUBJECT=9 REP=2

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
307	G	S	1	R	B	6	3
308	G	S	2	C	B	4	3
309	G	S	3	9	A	5	4
310	G	S	4	9	B	6	3
311	G	S	5	R	B	4	3
312	G	S	6	C	A	5	2
313	G	S	7	C	B	6	2
314	G	S	8	9	B	4	2
315	G	S	9	R	A	5	3
316	G	S	10	R	B	5	2
317	G	S	11	C	A	6	2
318	G	S	12	9	B	5	2
319	G	S	13	R	A	6	3
320	G	S	14	C	A	4	2
321	G	S	15	C	B	5	2
322	G	S	16	9	A	6	3
323	G	S	17	R	A	4	2
324	G	S	18	9	A	4	2

------------------------------ SUBJECT=10 REP=1 ------------------------------

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
325	G	F	1	9	A	4	7
326	G	F	2	9	B	4	6
327	G	F	3	R	A	5	8
328	G	F	4	R	B	6	5
329	G	F	5	C	B	4	5
330	G	F	6	9	A	5	4
331	G	F	7	9	B	6	4
332	G	F	8	R	B	4	5
333	G	F	9	C	A	5	4
334	G	F	10	C	B	6	3
335	G	F	11	C	A	4	4
336	G	F	12	C	B	5	5
337	G	F	13	9	A	6	5
338	G	F	14	R	A	4	4
339	G	F	15	R	B	5	3
340	G	F	16	C	A	6	3
341	G	F	17	9	B	5	5
342	G	F	18	R	A	6	4

------------------------------ SUBJECT=10 REP=2 ------------------------------

OBS	TYPE	FS	SEQ	LUM	SCE	SPD	BCDGM
343	G	S	1	9	A	6	4
344	G	S	2	R	A	4	4
345	G	S	3	R	B	5	4
346	G	S	4	C	A	6	3
347	G	S	5	9	A	4	5
348	G	S	6	9	B	5	6
349	G	S	7	R	A	6	5
350	G	S	8	C	A	4	4
351	G	S	9	C	B	5	5
352	G	S	10	R	A	5	4
353	G	S	11	R	B	6	4
354	G	S	12	C	B	4	5
355	G	S	13	9	A	5	5
356	G	S	14	9	B	6	6
357	G	S	15	R	B	4	6
358	G	S	16	C	A	5	3
359	G	S	17	C	B	6	4
360	G	S	18	9	B	4	7

Appendix 7 : Raw data (Pairwise comparison) - Experiment 2

Explanations :

SEQ : Trial Number.

FS : Order of in a Pairwise Present

F : First
S : Second

LUM : Luminaires Type

R : Realistic
9 : 90 ^{o} Maximum Candlepower
C : Constant

SCO : Relative Rating Score

SUBJECT=1

OBS	REP	SEQ	FS	LUM	SCO
1	2	1	F	9	4
2	2	1	S	R	1
3	2	2	F	R	3
4	2	2	S	C	1
5	2	3	F	C	2
6	2	3	S	9	1
7	2	4	F	9	3
8	2	4	S	C	1
9	2	5	F	C	1
10	2	5	S	R	2
11	2	6	F	R	4
12	2	6	S	9	1

SUBJECT=2

OBS	REP	SEQ	FS	LUM	SCO
13	1	1	F	C	1
14	1	1	S	R	3
15	1	2	F	R	4
16	1	2	S	9	1
17	1	3	F	9	5
18	1	3	S	C	1
19	1	4	F	C	2
20	1	4	S	9	1
21	1	5	F	9	1
22	1	5	S	R	4
23	1	6	F	R	4
24	1	6	S	C	1

SUBJECT=3

OBS	REP	SEQ	FS	LUM	SCO
25	1	1	F	R	4
26	1	1	S	9	1
27	1	2	F	9	5
28	1	2	S	C	1
29	1	3	F	C	1
30	1	3	S	R	1
31	1	4	F	R	5
32	1	4	S	C	1
33	1	5	F	C	1
34	1	5	S	9	3
35	1	6	F	9	6
36	1	6	S	R	1

SUBJECT=4

OBS	REP	SEQ	FS	LUM	SCO
37	2	1	F	C	1
38	2	1	S	R	1
39	2	2	F	R	1
40	2	2	S	9	3
41	2	3	F	9	8
42	2	3	S	C	1
43	2	4	F	C	1
44	2	4	S	9	7
45	2	5	F	9	3
46	2	5	S	R	1
47	2	6	F	R	2
48	2	6	S	C	1

SUBJECT=5

OBS	REP	SEQ	FS	LUM	SCO
49	2	1	F	9	1
50	2	1	S	R	1
51	2	2	F	R	1
52	2	2	S	C	1
53	2	3	F	C	1
54	2	3	S	9	1
55	2	4	F	9	4
56	2	4	S	C	1
57	2	5	F	C	1
58	2	5	S	R	3
59	2	6	F	R	1
60	2	6	S	9	3

SUBJECT=6

OBS	REP	SEQ	FS	LUM	SCO
61	1	1	F	R	1
62	1	1	S	C	3
63	1	2	F	C	1
64	1	2	S	9	3
65	1	3	F	9	3
66	1	3	S	R	1
67	1	4	F	R	1
68	1	4	S	9	5
69	1	5	F	9	5
70	1	5	S	C	1
71	1	6	F	C	1
72	1	6	S	R	3

SUBJECT=7

OBS	REP	SEQ	FS	LUM	SCO
73	1	1	F	C	4
74	1	1	S	R	1
75	1	2	F	R	1
76	1	2	S	C	1
77	1	3	F	9	9
78	1	3	S	R	1
79	1	4	F	9	4
80	1	4	S	C	1
81	1	5	F	C	1
82	1	5	S	9	7
83	1	6	F	R	1
84	1	6	S	9	6

SUBJECT=8

OBS	REP	SEQ	FS	LUM	SCO
85	1	1	F	9	1
86	1	1	S	R	3
87	1	2	F	R	1
88	1	2	S	C	4
89	1	3	F	C	1
90	1	3	S	9	5
91	1	4	F	9	3
92	1	4	S	C	1
93	1	5	F	C	3
94	1	5	S	R	1
95	1	6	F	R	1
96	1	6	S	9	1

SUBJECT=9

OBS	REP	SEQ	FS	LUM	SCO
97	1	1	F	9	3
98	1	1	S	C	1
99	1	2	F	C	1
100	1	2	S	R	1
101	1	3	F	R	1
102	1	3	S	9	1
103	1	4	F	9	1
104	1	4	S	R	3
105	1	5	F	R	3
106	1	5	S	C	1
107	1	6	F	C	1
108	1	6	S	9	1

SUBJECT=10

OBS	REP	SEQ	FS	LUM	SCO
109	1	1	F	C	1
110	1	1	S	9	4
111	1	2	F	9	3
112	1	2	S	R	1
113	1	3	F	R	4
114	1	3	S	C	1
115	1	4	F	C	1
116	1	4	S	R	3
117	1	5	F	R	1
118	1	5	S	9	2
119	1	6	F	9	3
120	1	6	S	C	1

SUBJECT=11

OBS	REP	SEQ	FS	LUM	SCO
121	2	1	F	9	6
122	2	1	S	R	1
123	2	2	F	R	3
124	2	2	S	C	1
125	2	3	F	C	1
126	2	3	S	9	1
127	2	4	F	9	3
128	2	4	S	C	1
129	2	5	F	C	2
130	2	5	S	R	1
131	2	6	F	R	4
132	2	6	S	9	1

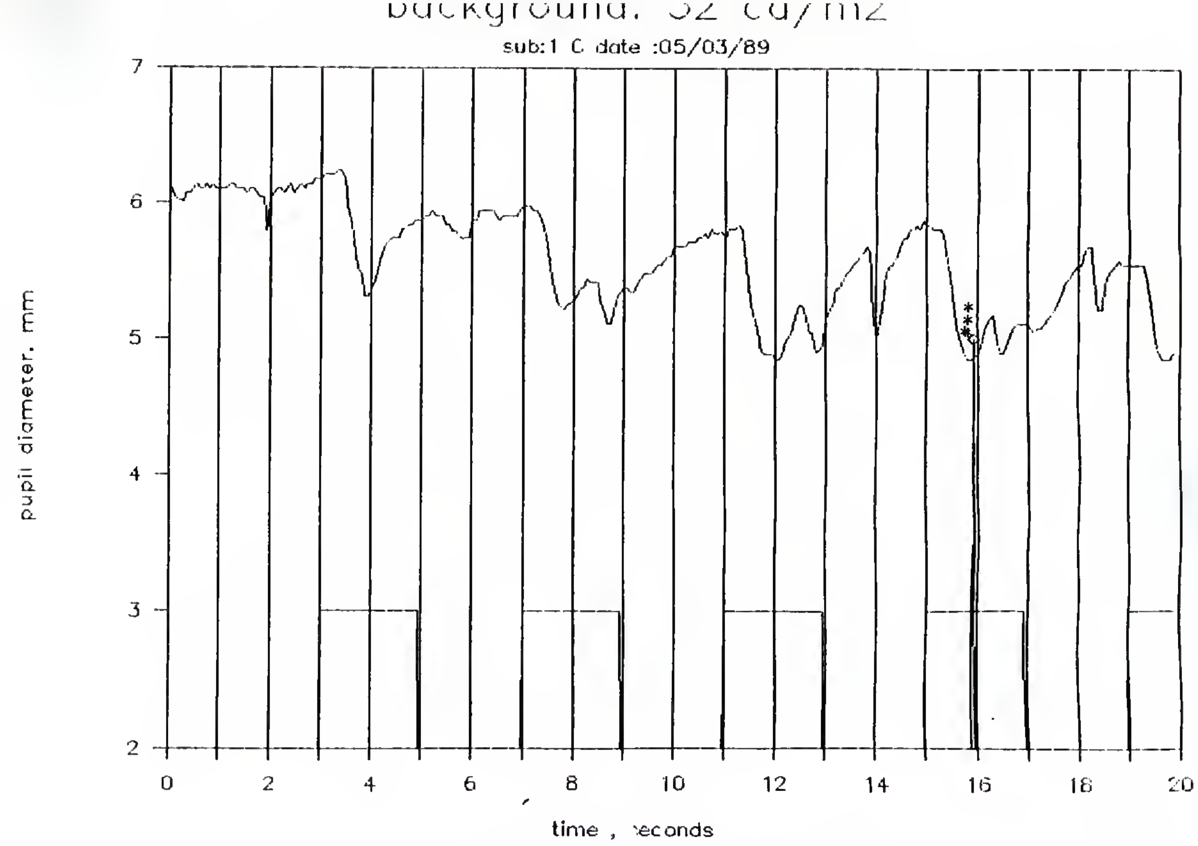
SUBJECT=12

OBS	REP	SEQ	FS	LUM	SCO
133	2	1	F	9	4
134	2	1	S	R	1
135	2	2	F	R	3
136	2	2	S	C	1
137	2	3	F	C	2
138	2	3	S	9	1
139	2	4	F	9	3
140	2	4	S	C	1
141	2	5	F	C	2
142	2	5	S	R	1
143	2	6	F	R	1
144	2	6	S	9	3

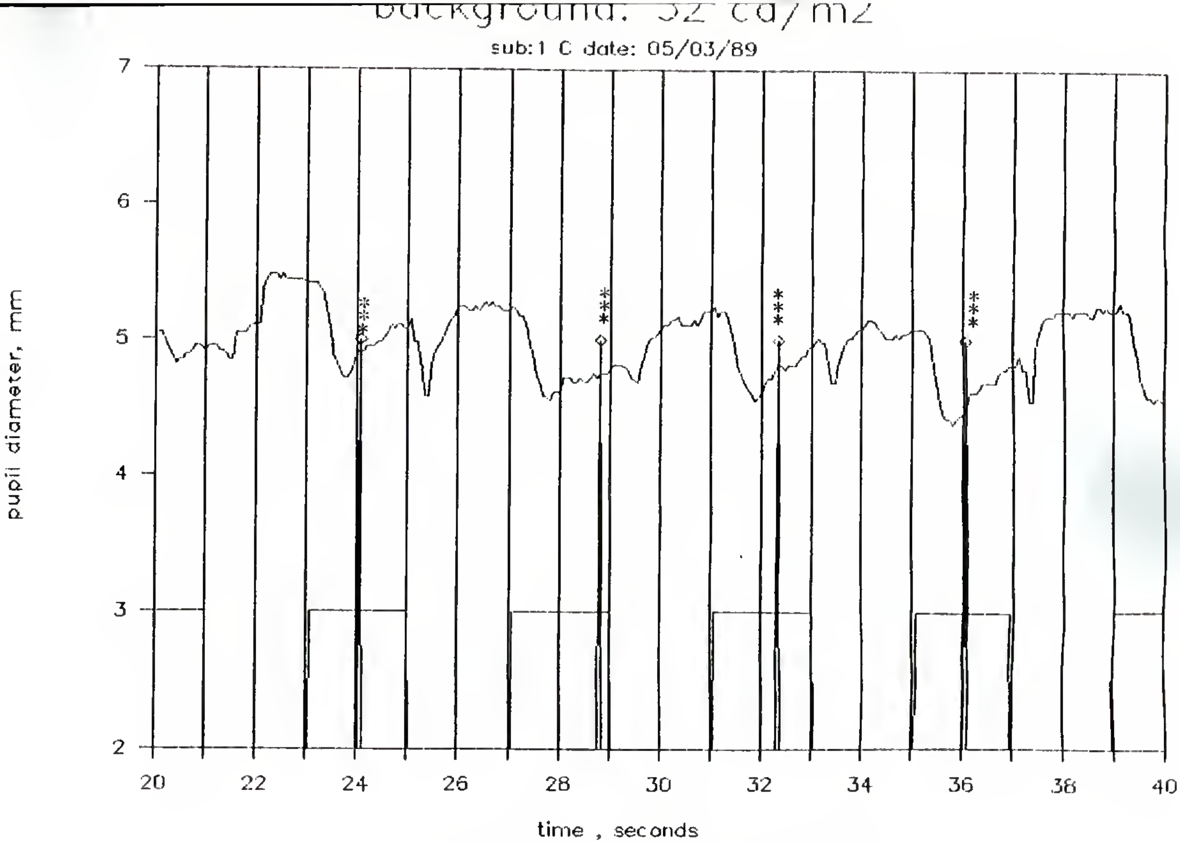
Appendix 8 : Pupil fluctuation chart- experiment 3

Explanations :

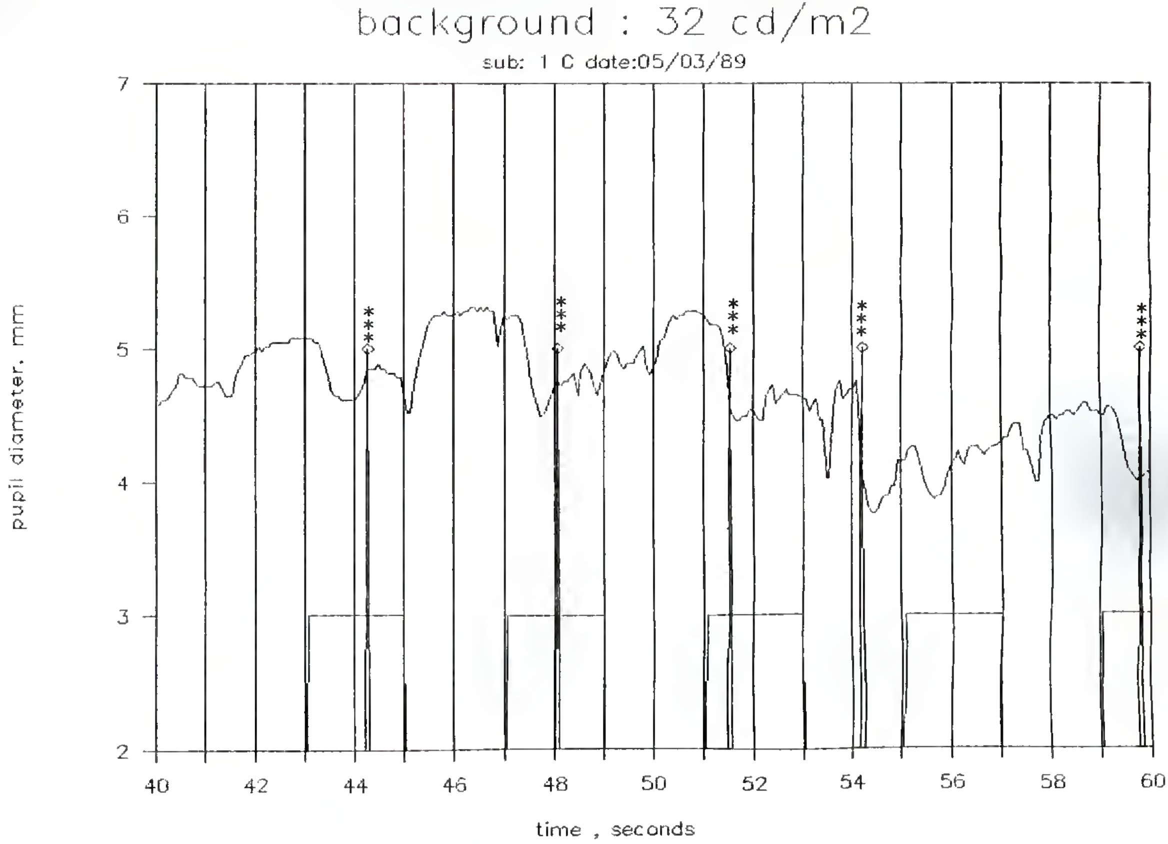
: Point that subject passed BCD, going up or down



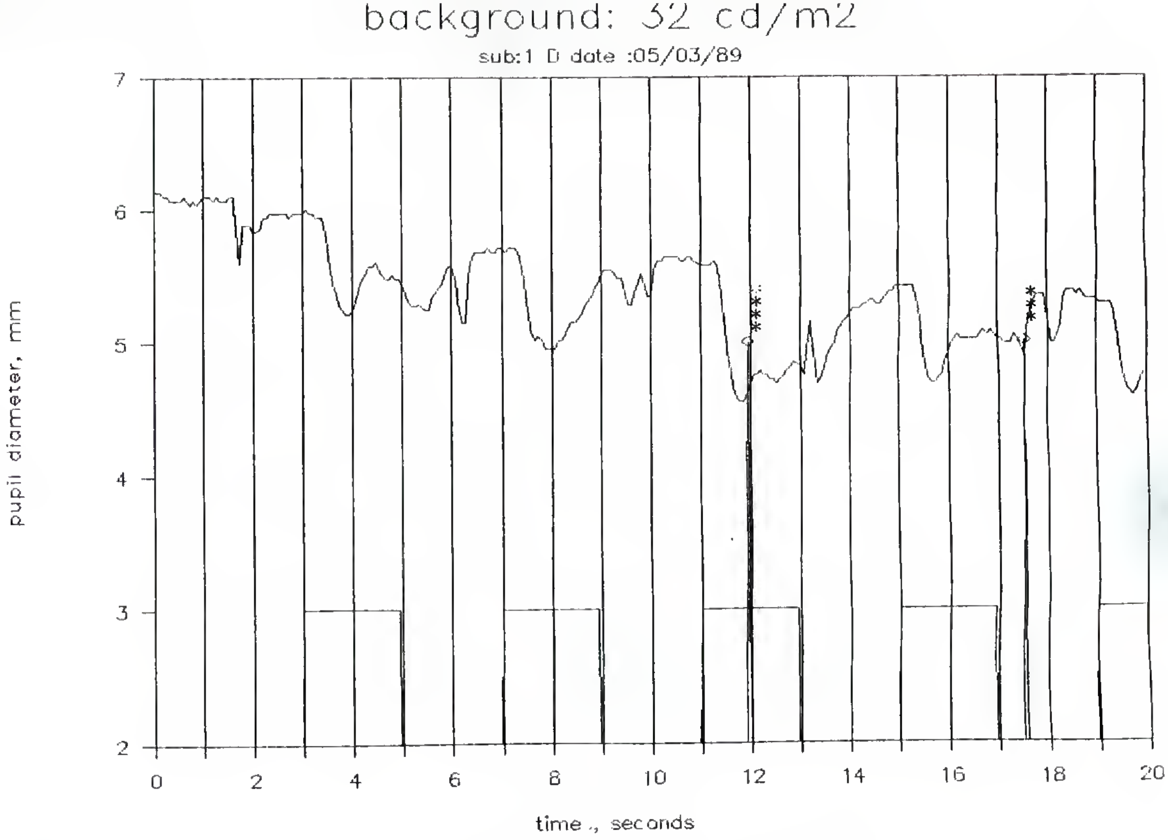
Subject 28, Trial 3, 0-20 seconds.



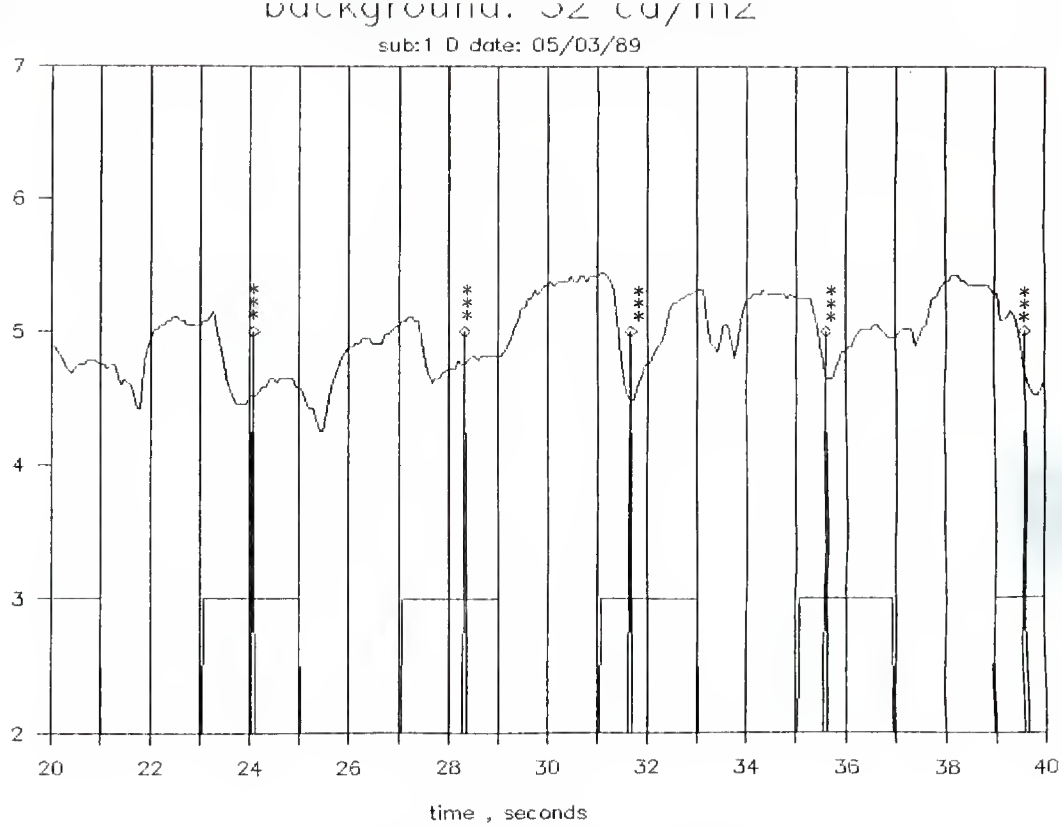
Subject 28, Trial 3, 20-40 seconds.



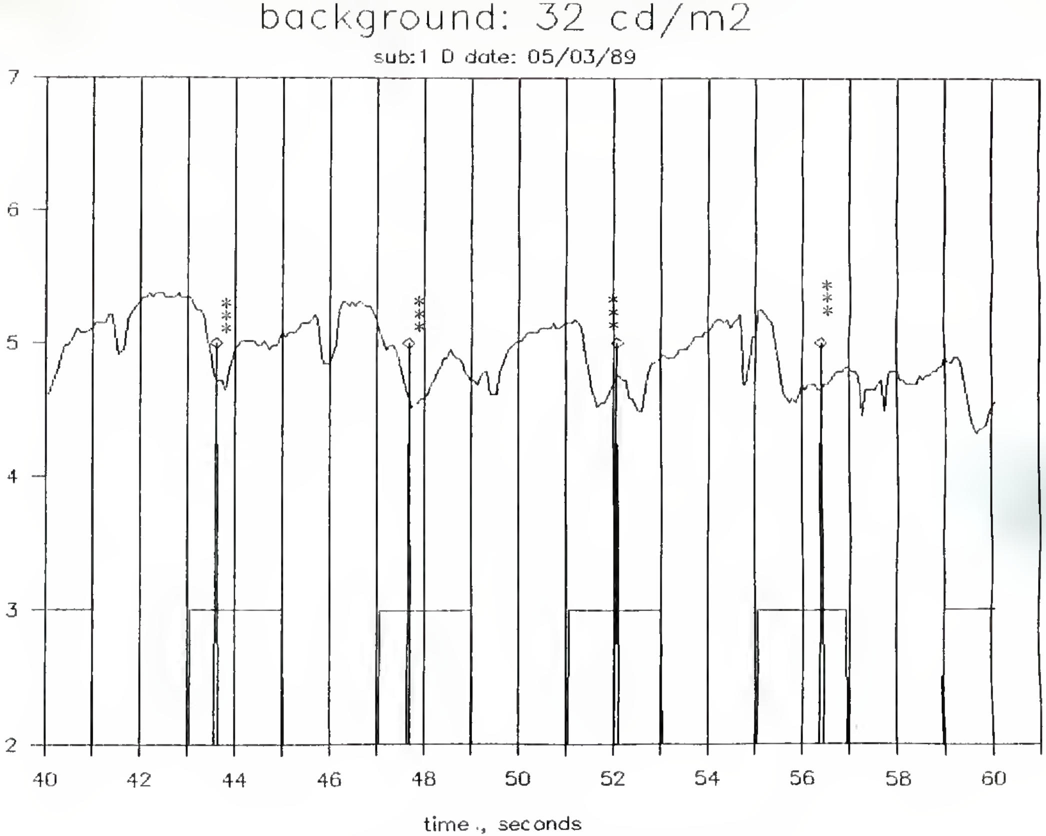
Subject 28, Trial 3, 40-60 seconds.



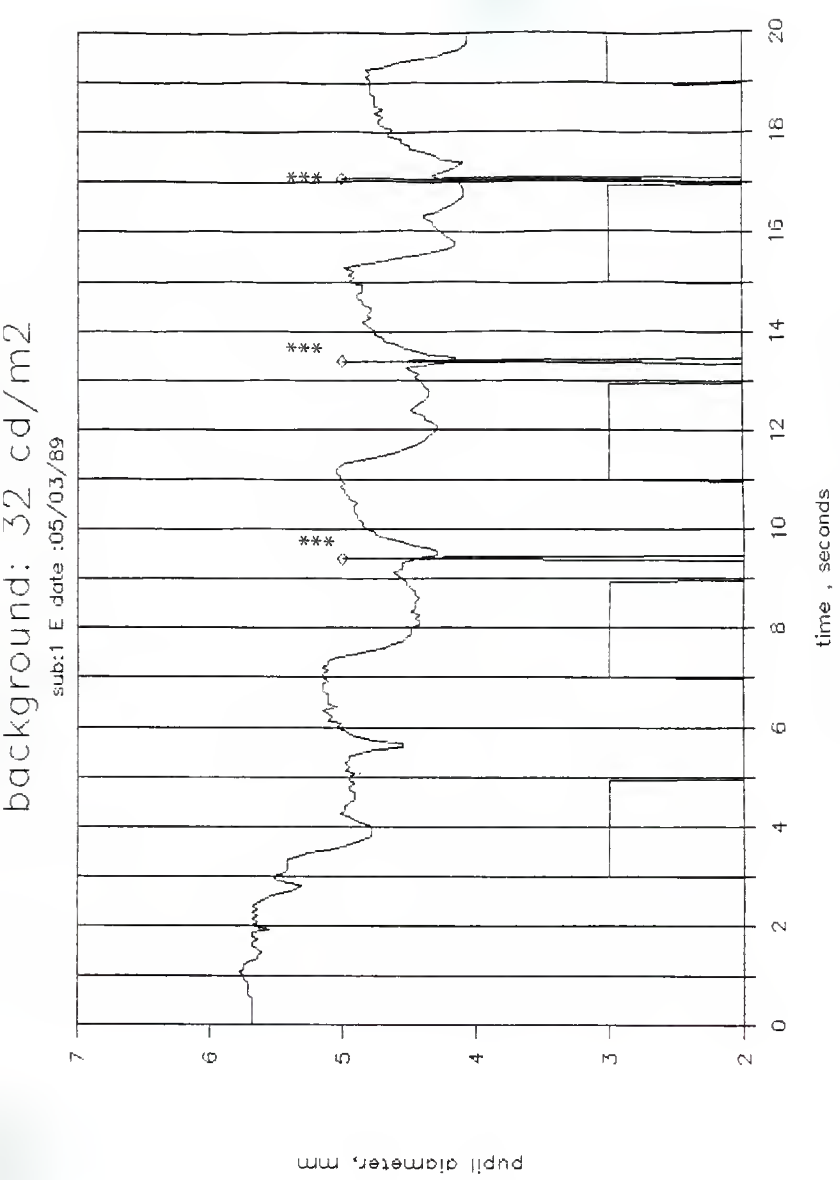
Subject 28, Trial 4, 0-20 seconds.



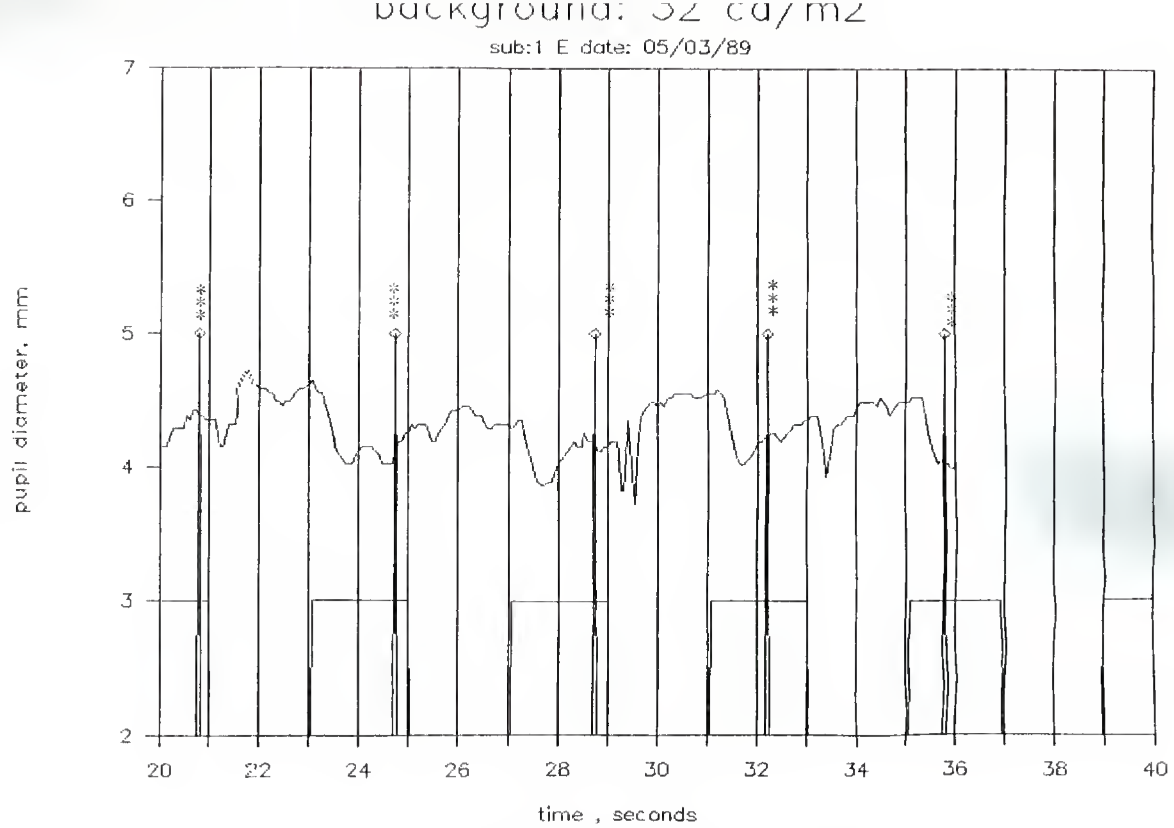
Subject 28, Trial 4, 20-40 seconds.



Subject 28, Trial 4, 40-60 seconds.



Subject 28, Trial 5, 0-20 seconds.



Subject 28, Trial 5, 20-36 seconds.

DISCOMFORT GLARE

LUMINAIRE LIGHT DISTRIBUTION, VEHICLE SPEED AND BACKGROUND

IN A DYNAMIC ROADWAY LIGHTING SIMULATION

BY

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B.E.(Industrial Engineering), National Tsing Hua University,
Tsin Chu, Taiwan. 1983

AN ABSTRACT OF A MASTER'S THESIS

Submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Industrial Engineering

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1989

ABSTRACT

Three experiments on discomfort glare are described.

In Exp. 1, 52 subjects adjusted the luminance to BCD from two initial luminances (2,600 and 34,700 cd/m ^{2}). The trials were divided into practice and criterion. The BCD value was significantly affected by initial luminance. The higher the initial luminance, the higher the BCD. The time to reach BCD was significant less in trials 6 - 11 than in trials 2 - 5. From the 52 subjects, ten subjects with the capability to recognize BCD consistently and with a "non-extreme" BCD were chosen.

In Exp. 2, 10 subjects were used. Three types of luminaire distributions, two types of road scenes and three car speeds (40, 50, 60 mph) were examined using two criteria (Glaremark and BCD). The luminaire distribution also was investigated using relative rating. All three criteria were significantly different for all three luminaires. The 90 $^{\circ}$ maximum candle power luminaire was most comfortable, the realistic luminaire was next and the constant luminaire was the least comfortable. This result disagrees with the results of Ganesh. Among the three criteria, the relative rating was most sensitive, the BCD next, and the Glaremark least sensitive. The Glaremark and BCD are relatively poor predictors of CBE, the relative rating is a good predictor of CBE. The effect of scene and speed were not significant using any of the criteria.

In Exp. 3, two subjects were used. The pupil diameter was recorded during the BCD adjustment procedure. The result showed that there is no evidence to conclude that PSI can be an index of BCD.